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Bituminous Coal (Courtesy R. Thiessen)

Frontispiece.

COAL

ITS PROPERTIES, ANALYSIS, CLASSIFICATION, GEOLOGY, EXTRACTION, USES AND DISTRIBUTION

BY

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NEW YORK

JOHN WILEY & SONS, Inc.

London: CHAPMAN & HALL, Limited

1922

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PREFACE

This work has been prepared in an attempt to satisfy the demand for a handy volume on coal. There already exists a very valuable literature on this important subject, but it is so voluminous and scattered that much of it is not accessible to the average reader. Many of our older works need revision because of new discoveries in the study of coal, such, for example, as the practical application of the microscope in the determination of its physical character and the discovery of more refined chemical processes for determining its chemical properties. The great advances in extracting coal from the earth by mechanical means and in the cleaning and coking of the products of the mine also make it necessary to bring new processes to the attention of the public.

There are so many different phases in the discussion of a subject so broad as this that details regarding many matters must be omitted in a one-volume work, and readers desiring detailed descriptions of machines or complicated processes must consult works dealing with those matters alone. While many topics are fully dealt with in this text, such as the properties, the origin, the uses and the general distribution of coal, some others as mining machinery, and details of distribution and character of local coal deposits can be treated only in works of several volumes. It is hoped, however, that the data presented will serve, for ready reference, those who make frequent use of a work of this type.

I wish to take this opportunity of expressing my appreciation to those who have so generously contributed to this work. My thanks are specially due to Dr. H. Ries of Cornell University, at whose suggestion the preparation of this text was undertaken, for suggestions and the use of photographs and cuts. I am also particularly obligated to my friend, Professor A. Lacroix, Secrêtaire perpêtuel de l'Académie des Sciences, Paris, for many favors, such as access to the library of the Academy and to valuable collections, including Ren-

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ault's slides on which he made his original study of bacteria in coal. The late Dr. Charles R. Zeiller kindly placed at my disposal his works on plant fossils and the coal basins of France, and Monsieur Peyerimhoff de Fontenelle, President, le Comité Central des Houillères de France generously presented me with a copy of the splendid work, Atlas Général des Houillères, by E. Gruner and G. Bousquet. Dr. Aubrey Strahan, Director of the Geological Survey of England and Wales kindly supplied an advance copy of one of his works in addition to other original data. My thanks are due also to Dr. D. F. McFarland, and to Dr. J. B. Hill of the Pennsylvania State College, for criticism of the chapters dealing with the chemistry of coal and with paleobotany; to Professor A. L. Kocher for retouching photographs, and to several of my students who aided greatly in copying diagrams, sections and other material.

Although acknowledgment has been made in the text to those from whom photographs and plans have been received, I wish to mention particularly the officials of the Twelfth International Geological Congress, Dr. F. D. Adams, President, who kindly granted me permission to republish the various maps in the report on the Coal Resources of the World. I am also indebted to *Coal Age*, the Barrett Company, the Delaware and Hudson Company, the Koppers Company and the Semet-Solvay Company for the privilege of reproducing illustrations. Photographs or drawings were generously contributed by Dr. R. Thiessen of the United States Bureau of Mines, the Director of the United States Geological Survey, Dr. E. C. Jeffrey of Harvard University, Dr W. R. Crane, Mr. Francis Harper, the Hillman Coal Company, the Sullivan Machinery Company, the Bethlehem Fabricators, the Ebensburg Coal Company and Mr. John Bevan of Pottsville, Pa. In addition to those persons and organizations specifically mentioned, there are many of my friends and colleagues who have furnished information which has been very helpful, and their interest and aid have been much appreciated.

ELWOOD S. MOORE

STATE COLLEGE, PA.
October 27, 1921.

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COAL

CHAPTER I

THE PHYSICAL PROPERTIES OF COAL

Introduction

History. — The first mention of coal in literature dates from the fourth century, B. C., but so rapidly has its use developed that it has become one of the most important among all commercial factors. The enormous production of approximately 1,478,000,000 short tons[1] for the year 1913, the last year of normal production before the great war, indicates how useful a commodity it is to the world. This output reckoned at the average price of the coal, as sold at the mine throughout the United States for the same year, would reach the sum of $1,965,740,000, while if it were computed at the price prevailing in England or France it would be from nearly two to two and one-half times this amount. Scarcely any home or industrial concern among white races can exist without its use, directly or indirectly, although as recently as the reign of Henry II of France it was considered so objectionable a fuel that the smiths in Paris obtained a special license or paid a fine for using it. There were regulations against its use in many of the cities of Europe during the seventeenth century although it began to enter actively into trade in England about the thirteenth century. Mining did not, however, become very extensive until after the invention of the steam engine. In America the first bituminous coal mining began in Virginia in 1787 and the first recorded shipments of anthracite were made about 1805, although anthracite was discovered about the year 1762, and bituminous coal in 1679. The earliest records of production of bituminous coal in this country date from 1820, when 3000 tons were produced. In 1814 there were 22 tons of anthracite recorded. The million-ton

[1] Mineral Resources, U. S. Geol. Survey, 1914, Pt. 2, p. 639.

mark was first passed for anthracite in 1837 and for bituminous coal in 1850.

History shows that no country has reached an eminent industrial position which has not had large supplies of coal within its borders or had ready access to them. Reference to the prominent nations of the present day proves that coal and iron have been two essential factors in their development.

It has been said that the Chinese knew the use of coal to a slight extent before the Greeks did, but the first definite record of its utilization is found in Aristotle's Meteorology.[1] Speaking of the combustible bodies he says, "Those bodies which have more of earth than of smoke are called coal-like substances." Theophrastus, a pupil of Aristotle, and Pliny both mention this substance and its use by the smiths. The coal mentioned in these writings was evidently all of the brown-coal variety, and it came from Thrace in northern Greece and from Liguria in northwestern Italy. It thus became known to the ancients as Thracius lapis and gemma Samothracia, while *jet* which came from Lycia in Asia Minor, was called Gagates after a river in that region.

The word *coal*, as now used, is derived from the Saxon *col*. It was always *cole* in English until sometime in the seventeenth century, and *coal* then referred to *charcoal* as that term is now employed. At the present time the term *coals* is employed in two senses, one meaning glowing fragments of some combustible substance and the other the different varieties of the material known in a general way as *coal*. The Germans use for coal the term *Steinkohle* and the French speak of it as *charbon* or *charbon de terre*.

Coal a rock, not a mineral. — Coal is the term applied to vegetal matter with varying amounts of mineral matter and with or without small proportions of animal matter, which through geological processes has become so changed by loss of volatile constituents that it is more or less compact and dark in color. It burns with comparative slowness and decomposes slowly in the atmosphere. It has a variable chemical composition and it is not homogeneous. It grades into peat, and differs from that substance in composition chiefly in the smaller percentages of water, oxygen and volatile hydrocarbons which it contains. It is frequently spoken of as *mineral coal*[2] and in the

[1] Book IV, Chap. 9, Sections 36–37. (French translation by B. S. Hilaire.)

[2] Dana, E. S., System of mineralogy, 6th ed., 1892, p. 1021.

United States coal lands are classed under the division of Mineral Lands. It is not, however, a mineral in the strict sense of the term because a mineral, as defined by Dana,[1] must be inorganic, homogeneous, and have a definite chemical composition, all three of which requirements coal lacks. Yet it might be questioned whether the varying amount of impurity in the form of ash in the coal is not somewhat analogous to the impurities which are present in some minerals producing coloring effects and variation in other physical properties, and also whether the chemical formulae for some of the complex silicates, such as members of the amphibole group, do not vary almost as much as those for some varieties of coal when ash and moisture are eliminated.

Although not a mineral, coal is a rock, since the geologist regards as rocks all natural, solid substances, organic or inorganic, which compose the earth's crust. It is as much a rock as are sandstone and limestone, and when one attempts to classify the different varieties of coal he meets with the same difficulties experienced in classifying other rocks, for the reason that Nature does not draw sharp lines between varieties. It is just as difficult to decide in some cases whether a certain coal is bituminous coal or anthracite as it is to determine when a shale, high in lime, passes into a limestone, or when an igneous rock by variation ceases to be a syenite and becomes a diorite. As a result of this lack of definiteness in the delineation of our varieties of coal, many attempts have been made in recent years to devise some concise method of classifying coals so that all the terms employed will have some definite meaning. These attempts have met with some of the same difficulties encountered by the petrographers who have attempted the quantitative classification of igneous rocks. Some of the objections are that in many cases elaborate chemical analyses are required, and in most cases the chemical and physical properties and the field characteristics are not closely enough related to make the classification readily applicable to all varieties under all conditions.

[1] A textbook of mineralogy, p. 1.

Physical Properties

In the description of the varieties of coal certain common physical and chemical terms much used in mineralogy are employed. The physical properties include specific gravity, hardness, fracture, color, streak, luster, and physical constitution or texture. These are the properties by which the public recognizes the different varieties of coal in the trade, but the chemical composition is the determining factor in the value of coal.

Specific gravity. — The specific gravity of a body is the ratio of its weight to the weight of an equal volume of water at 4° C. When the average specific gravity of a quantity of coal is known the space which a ton will occupy can be roughly determined, it being always remembered that the volume of a ton will vary with the size to which the coal is broken. The gravity of the common varieties of coal varies as follows: Lignite 0.5–1.30; Bituminous coal 1.15–1.5; Cannel 1.2–1.3; Anthracite 1.29–1.65.

There are various methods for determining the specific gravity of coal. It may be determined approximately for compact fragments by drying the specimen carefully, weighing it in air (weight = W), and then in water (weight = W_1). Since the specimen loses in weight an amount equal to the weight of the water displaced, i.e., the weight of its own volume of water, the specific gravity is found from the following formula: $G = \frac{W}{W - W_1}$. For a more accurate determination of the solid substance with the pores omitted the specimen should be boiled in water in order that the air may be expelled from the pores. On the other hand, if the specific gravity of a given mass of coal with all pores included is desired the body should be coated with a thin veneer of paraffin or varnish to exclude all water from the pores.

Determination by use of pycnometer: Accurate laboratory determinations may be made on powdered coal by using the pycnometer. This is a glass vessel which when filled to a specified mark contains a given weight of water at a certain temperature. The dry powder is weighed in air (weight = W). The pycnometer is weighed full of water (weight = W_1), and then emptied. The powder is then placed in the vessel, all air is excluded, the water is brought to the

same level as before the coal was added and the vessel is weighed (weight = W_2). The specific gravity is then obtained from the following formula $G = \frac{W}{W + W_1 - W_2}$.

The following methods for determining the specific gravity of coal and coke are used in the fuel-testing laboratories of the United States Bureau of Mines.[1] To determine the true specific gravity the pycnometer is ordinarily employed and about 3.5 grams of the 60-mesh coal or coke is used as a sample. About 30 c.c. of distilled water is employed in a 50-c.c. pycnometer, and the water is thoroughly boiled after the sample is placed in the bottle, for the purpose of excluding all air. The boiling is done on a water-bath and to avoid loss of particles of the coal or coke a one-bulb, 6-inch drying tube is connected with the pycnometer by means of a small piece of pure gum tubing. This drying tube is then attached to an aspirator and suction is applied while the water in the flask is gently boiled for three hours. The tube is then detached, the flask removed from the bath, and almost filled with water previously boiled and cooled. When cooled to the temperature of the room at which original weighing was made, the pycnometer is stoppered and weighed. The formula employed is the same as that given above, $G = \frac{W}{W + W_1 - W_2}$.

Determination by Hogarth-flask: A special method is recommended as being more convenient and accurate for routine determinations than the pycnometer method. This consists in the use of a Hogarth flask such as that used in determining the specific gravity of iron ores. (Fig. 1.) This flask has a capacity of 100 to 125 c.c. To make the test a 10-gram sample of 60-mesh coal or coke is weighed and introduced into the weighed flask together with sufficient distilled water to fill it half full. The flask is placed on a small electric hot plate inside a 10-inch vacuum desiccator and the latter is evacuated by an aspirator or air pump. The water in the flask is kept boiling and the air is expelled in thirty minutes with a good air pump. The flask is then removed from the desiccator and filled to the tubulure with

FIG. 1. Hogarth's specific gravity flask.

[1] Stanton, F. M., and Fieldner, A. C., Tech. Paper 8, 1913.

distilled water which has recently been boiled and cooled. The stopper is inserted after having been coated with a thin film of vaseline to prevent leakage.

After the flask has cooled to about 25° C. in a water thermostat, distilled water that has been cooled in the same thermostat is drawn through the tubulure until the water level is slightly above the mark on the capillary of the stopper. If the end of the tubulure be inserted in a small beaker of water and a slight suction applied to the stopper this operation may be performed without removing the flask from the thermostat. The flask should be left in the thermostat until the temperature is 25° C. The water level may be adjusted to the mark in the capillary by drawing in a little water. When this is done the flask is removed, wiped dry, and weighed. The true specific gravity is then found by the formula used in the previously described test.

Hydrometer method: To determine the *apparent* specific gravity an apparatus is used which consists of a brass hydrometer immersed in a galvanized-iron cylinder filled with water to a water-line. There are two pans on the top of the hydrometer, the upper one being used for weights and the lower for the sample of coal or coke. Below the copper air buoy there is a brass cage highly perforated so as to allow the air to escape during immersion. This cage carries the sample when it is weighed under water.

To determine the specific gravity with this apparatus, brass weights are placed on the upper pan causing the hydrometer to sink to a mark on the stem between the pan and the buoy. This weight is designated by (W). The weights are removed and about 500 grams of the sample in $1\frac{1}{2}$ to 2 inch cubical lumps is placed in the copper dish. Weights are again added until the instrument sinks to the same mark on the stem as it did previously, (weight = W_1). The sample is then transferred to the perforated cage and weights are added until the same mark on the stem again touches the surface of the water; (weight = W_2). We now have the following, $(W - W_1)$ = weight of sample in air, and $(W - W_2)$ = weight of sample in water. Since the body loses in weight when weighed in water an amount equal to the weight of the water displaced the apparent specific gravity =

$$\frac{W - W_1}{(W - W_1) - (W - W_2)}.$$

Further, in determining the specific gravity of coke $100 \times \frac{\text{apparent specific gravity}}{\text{true specific gravity}}$ = percentage by volume of coke substance, and 100 − percentage by volume of coke substance = percentage by volume of cell space.

Certain precautions are observed in making *apparent* specific gravity tests on coke. It should preferably be in lumps of nearly the same size and shape, and when the sample is immersed the hydrometer should be moved rapidly up and down a few times to remove air bubbles. Coke samples, because of their marked porosity, should not remain in the water more than five minutes and all specimens of coal or coke should be thoroughly dried before tests are made.

Use of heavy solutions in determination of specific gravity: In an investigation of the Canadian coals Porter and Durley[1] used a heavy solution consisting of calcium chloride and calcium nitrate mixed so as to obtain required densities. The crushed coal was placed in this solution and separated, the heavier sinking, the lighter rising to the top, and that of the same gravity as the solution floating suspended in the liquid.

Gravity of "ash-free" and "moisture-free" specimens: In case it is desired to obtain the specific gravity of the pure fuel with moisture and ash excluded a correction must be made for these. The actual specific gravity of the ash may be obtained, or, as Pollard[2] suggests, the correction for ash may be made with a sufficient degree of accuracy for all practical purposes by deducting 0.01 from the specific gravity of the coal for each per cent ash.

As a rule, high-carbon coals have higher specific gravities than those low in carbon because of their more compact character. It might be expected that the percentage of ash would be the factor controlling the specific gravity of the coal in all cases since the mineral matter entering the ash has, as a rule, a higher specific gravity than the materials forming the combustible portion of the fuel, and this is generally true if the proportions of the other constituents remain

[1] Porter, J. B., and Durley, R. J., An investigation of the coals of Canada. Canada Dept. of Mines, Vol. 1, pp. 194 and 199, 1912.

[2] Strahan, A., and Pollard, W., The Coals of South Wales with special reference to the origin and distribution of anthracite. Memoirs of the Geol. Survey of England and Wales, 2d ed., p. 12, 1915.

constant. It is found, however, from a study of a large number of analyses that there is no regular ratio between the percentage of ash and the specific gravity, and this seems to be due to a variation in the volatile constituents, and the compactness of the fuel. It depends also upon the nature of the ash since the presence of iron compounds tends to raise the specific gravity above that for silica, alumina and many other constituents.

That the specific gravity has a direct bearing on the burning qualities of the coal is seen in the statement of Porter and Durley,[1] who conclude as a result of their investigation of Canadian coals that few, if any, coals which have a specific gravity over 1.6 are worth burning and that, excepting the anthracites and perhaps one or two special types of coals, the approximate limit for commercially profitable coals is 1.55. They add further that the pure bituminous coals of Canada have a specific gravity between 1.265 and 1.325.

Hardness. — The hardness of coal varies from that of the soft lignites to that of the hard anthracites. It is difficult to state any definite hardness for the coals other than anthracite because they vary so much in different portions of the same fragment. Anthracite varies from 2 to 2.5 in Moh's scale of hardness, which means that it can be scratched with difficulty by the finger nail.

Fracture. — The fracture in coal is a very important determining factor in recognizing the ordinary types in hand specimens. The anthracites break with a conchoidal fracture, i.e. the fracture leaves a concave surface like that of a shell. This is characteristic also of cannel coal, but the other varieties of bituminous coal generally break with a rectangular or cubical fracture. The lignites fracture so that, as a rule, they break into roughly tabular or flat, elongated fragments. (Plates III and IV.)

In coal beds there are usually two sets of joints resulting from the drying out of the rocks and the movement of the strata and these run approximately normal to each other. Those which lie normal to the strike and cut across the bedding of the coal are frequently known as *cleats*. They are, as a rule, more clearly marked than the joints running in the other direction.

Color and streak. — The color of coal varies from light to dark brown in the lignites to grayish black and jet black in the higher

[1] Op. cit., p. 194.

grades. The *streak* is the color of the powder and it is determined by making a mark on a piece of unglazed porcelain. For the coals below bituminous it is brown to yellow. In bituminous coal it is brownish to black and in cannel it is brown to black. The streak of the higher-rank coals is black.

Luster. — The luster, or the manner in which the coal reflects light from its surface, is, like the fracture, often an important diagnostic property in a hand specimen. The anthracites have usually a bright to almost submetallic luster and the luster of natural coke is bright to submetallic, while that of cannel coal is usually, and that of mineral charcoal, always, dull to earthy. Slaty coal is dull. In bituminous coal there are interlayered bright and dull bands, the former representing portions of the coal formed from trunks or branches of trees, and the latter portions being made up of mineral charcoal and the smaller particles of vegetal matter or sometimes of impure earthy layers.

Physical constitution. — That coal has been derived almost entirely from vegetal matter is proven by the presence in lignite of abundant remains of plants and by the presence in decreasing amounts of distinctly recognizable plant remains in all the varieties of coal from lignite to anthracite. While some anthracite may not show a trace of woody tissue to the naked eye, or even under the microscope, some other portions of this coal from the same seam may show distinct evidence of the presence of vegetal constituents now altered to coal. The microscope has been of great service in recent years in aiding us in detecting the presence of altered vegetal remains in coals where they were not formerly recognized by the naked eye. The effects of the different kinds of vegetation or the different portions of the same types of vegetation which enter into the coal may now be recognized through the varying appearances of the coal produced from these different materials. It is found that the spores from the Cryptogamic plants which can be recognized under the microscope, if comparatively free from other materials will produce the dull-lustered cannel bands, the stems of trees usually produce bright bands in the coal, while resins generally produce light-colored spots or streaks. It has been found, therefore, that coal is usually made up of the following constituents: (*a*) distinctly woody or xyloid material, so abundant in lignite and to which Thiessen has given

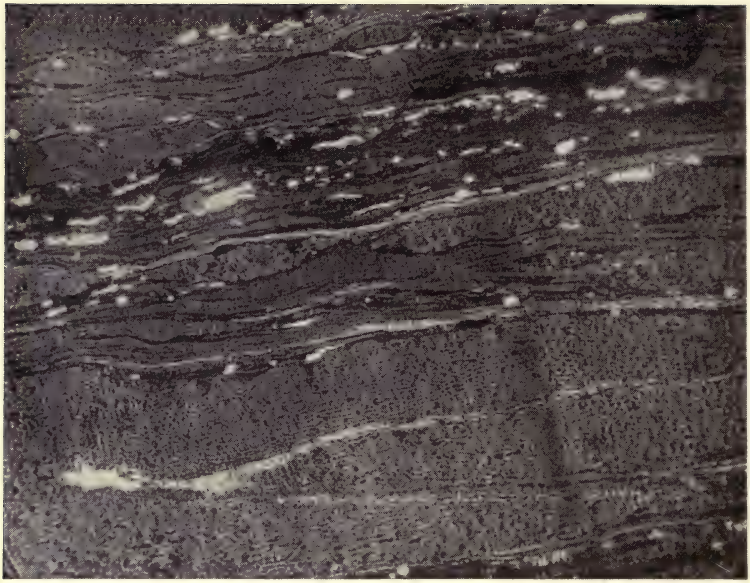


FIG. 1. Photomicrograph of coal from No. 6 seam, Royalton, Ill. (x 160). Distinct woody tissue and a few flattened spores are visible. (After R. Thiessen.)

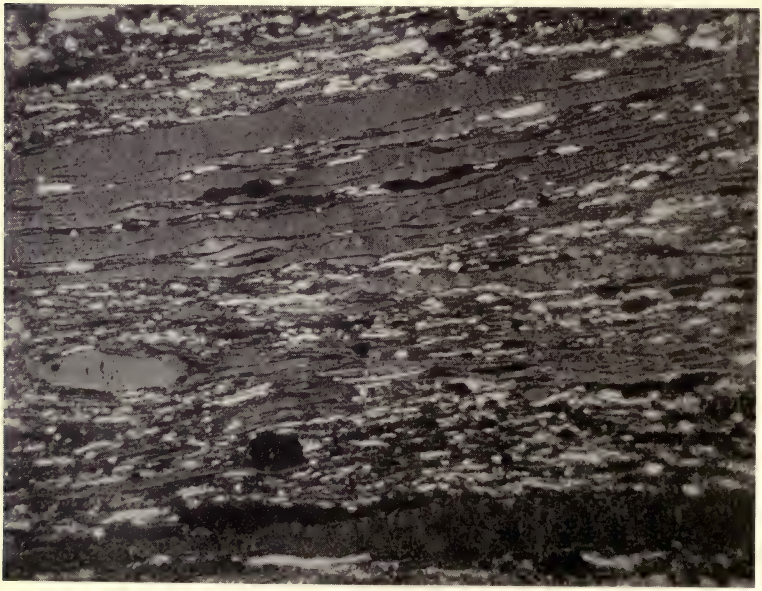


FIG. 2. Same as Fig. 1. Shows little xyloid tissue but many flattened spores as white lines.

the name anthraxylon, from the Greek *anthrax*, coal and *xylon*, wood. (*b*) canneloid, consisting chiefly of spores and forming the bulk of cannel coal; (*c*) resins found in all coals but especially evident in lignite and scarce in cannel; (*d*) débris, or the macerated material mixed with the woody matter and derived from a great variety of substances by the breaking up of stems, cells, cuticles, spores, and particles of resin; (*e*) the "fundamental matter,"[1] or the colloidal groundmass in which the other constituents of the coal are embedded and which is made up chiefly of the remains of the more readily decomposable parts of the vegetal matter. It seems to consist chiefly of fragments of cellulosic material, cuticles, cutinized cell walls, spore-exines, pollen-exines, fragments of wood fiber, bits of resin, and all the other finer particles of the material entering into the composition of the coal. Some authors consider that large quantities of algal remains are included in this substance and this subject will be discussed more fully in the chapter on the origin of coal

The Microscopic Study of Coal

Development of the microscopic study. — The subject of the physical constitution of coal has received a great deal of attention during the last century and a half, and the historic development of this study is well treated in the work by White and Thiessen. As early as 1778 Franz von Beroldingen[2] outlined a logical theory for the development of the coal swamps and for the origin of petroleum. In 1833 H. Witham[3] made what was probably the first microscopic examination of coal and his work was followed by that of Hutton.[4] In 1838 Link[5] boiled coal fragments in kerosene to render them more nearly transparent for microscopic study. In 1855 Franz Schulze[6]

[1] White, D., and Thiessen, R., The origin of coal. U. S. Bur. of Mines, Bull. 38, p. 227, 1913.

[2] Von Beroldingen, Franz, Beobachtungen, Zweifel, und Fragen, die Mineralogie überhaupt, und insbesondere ein natürliches Mineral System betreffend, vol. 1, 1st ed., 1778, 2d ed., 1792.

[3] Witham, Henry, On the internal structure of fossil vegetables found in the carboniferous and oölitic deposits of Great Britain, 1833.

[4] Hutton, W., Observations on coal. London and Edinburgh Phil. Mag. and Jour. of Science, vol. 2, p. 302, 1833.

[5] Link, Frederick, Uber den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen untersuchungen. Abhandl. k. Preuss. Akad. Wiss. Berlin, pp. 33–34, 1838.

[6] Schulze, Franz, Uber das Vorkommenwohlerhaltenes Cellulose in Braunkohle und Steinkohle; Ber. k. Akad. Wiss. Berlin, pp. 676–678, 1855.

adopted the maceration process for lignite and bituminous coal. He digested the material in a mixture of dilute nitric acid and potassium chlorate and then washed it in ammonium hydroxide and hot alcohol, thus isolating woody fibers.

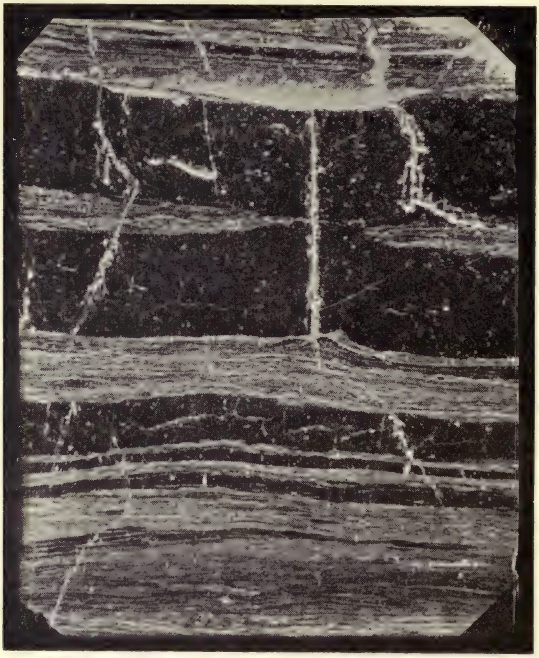


FIG. 2. Photomicrograph of bituminous coal showing bright bands due to woody material and dark bands due to débris. (Photo by Thiessen.)

The work of these investigators was followed by that of J. W. Dawson, C. W. von Gümbel, C. E. Bertrand, B. Renault, H. Potonie, O. Barsch, D. White, and E. C. Jeffrey, all of whom have paid particular attention to the microscopic characters of coal. It was not, however, until about 1910 that a satisfactory method was found for preparing thin sections for study. This was discovered by Jeffrey and described in his article published in that year.[1]

Preparation of thin sections. — In the preparation of thin sections with the microtome there are two chief operations necessary, one the removal of the mineral matter and the other the softening of the coal

[1] Jeffrey, E. C., The nature of some supposed algal coals. Proc. Am. Acad. of Arts and Sci., vol. 46, pp. 273–290, 1910.

so that it may be cut on the microtome like an ordinary botanical or zoölogical section. The chief agent used for the removal of the mineral matter, which consists mainly of silica, pyrite and carbonates, is hydrofluoric acid and the softening agent is potassium or sodium hydroxide. Jeffrey has recently concluded, however, that phenol is a still better softening agent since it does not cause so much swelling of the coal.[1] As to whether the hydroxide should have water or alcohol added to it or be employed hot or cold depends upon the resistance of the coal. Thiessen[2] points out that alcohol, by causing shrinkage, has the advantage of counteracting the expanding influence of the hydroxide but it causes a more violent reaction. For cannel Jeffrey[3] used a mixture of 70-per cent alcohol saturated with sodium or potassium hydroxide. He allowed the coal to stand in this for a week or more at a temperature of 60° to 70° C. until it was softened. The mixture was then carefully removed by hot alcohol and the fragments later treated with hydrofluoric acid for two or three weeks. After this treatment the acid was washed out very thoroughly so that no trace of it might attack the knife, the coal was embedded in celloidin to stiffen it, and was then cut on a microtome. The celloidin recommended is that known as *Schering's*. For those coals which are more resistant to the softening process he uses either aqua regia ($HNO_3 + 3\ HCl$) or nitric and hydrofluoric acid of full strength. He found that the acid treatment in many cases must be followed by a treatment with sodium or potassium hydroxide after the acid is removed. After the sections are cut they are dehydrated in a mixture of absolute alcohol and chloroform. One difficulty was experienced in preparing the sections for cutting; this was the fact that hot alcohol and ether must be used in embedding the specimens in the celloidin and these solvents dissolve some portions of the lower grades of coal.

After various experiments Thiessen recommends that mineral acids such as nitric acid, be avoided if possible, owing to their oxidizing action on the coal. In place of nitric acid alternate applications of hydrofluoric acid and potassium or sodium hydroxide may be used to soften resistant samples. In treating the samples with hydro-

[1] Jeffrey, E. C., Methods of studying coal. Conspectus, Vol. 6, No. 3, 1916.

[2] Thiessen, R., Op. cit., p. 207

[3] Jeffrey, E. C., Op. cit.

fluoric acid they should be placed in paraffin, ceresin, or rubber bottles rather than in lead. For lignite a good solution is one part commercial hydrofluoric acid and one part of 30 to 50 per cent alcohol in which the blocks, which have been cut about 2 to 4 millimeters square and 10 millimeters long, are placed until the mineral matter is dissolved. The acid may then be removed by potassium hydroxide or sodium hydroxide and the section cut on the microtome without further softening.

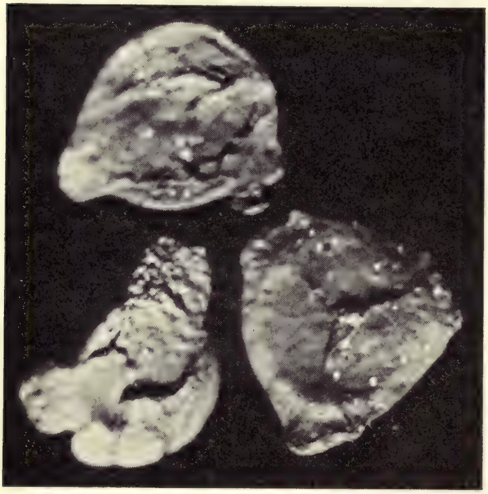


FIG. 3. Baxton megaspores from coal, with air sacks and showing tri-radiate lines (x 25). (After R. Thiessen.)

If the specimens are resistant and need softening a 5 per cent solution of sodium hydroxide in 50 per cent alcohol is used. If they are friable they may be embedded in paraffin but this must not be allowed to actually penetrate the coal. The sections may be bleached in nitric acid or Javel water. After dehydration they may be mounted on slides with Canada balsam.

Thiessen has, in his more recent work, abandoned the use of the microtome and adopted the grinding method since this has one distinct advantage over the slicing method.[1] By preparing the specimens in this way no part of the coal or its included foreign matter is removed by the acids or other reagents and all the features of the coal may be studied. It has a disadvantage, however, in that several sections cannot be cut from the same specimen of coal almost as easily as one. When the coal is once softened it is an easy task to cut on the microtome many sections from the same block, for the study of the internal structure of bodies occurring in the coal. The sections of anthracite or bituminous coal must be ground extremely

[1] White D., and Thiessen R., The origin of coal. Bull. 38, U. S. Bur. Mines. Also Thiessen R., Structure in paleozoic bituminous coals. Bull. 117, 1920.

thin to permit any light to pass through them and it is only after considerable practice that this grinding process can be successfully carried out.

In preparing the sections a block less than an inch in diameter is cut from the coal. The preliminary grinding is done with a paste of carborundum powder on a fine textured carborundum lap, then on the lap without any powder but with a stream of water playing on the lap. The specimen is then rubbed on a hone with a stream of water running over it until it is perfectly smooth and flat on the polished side. After this operation the specimen is waterproofed to prevent water entering the coal and causing it to swell. This process consists of soaking the polished surface, first heated to about 105° C., in paraffin heated to the same temperature. This requires only a few minutes.

After waterproofing, the specimen is cemented to a slide with a strong, transparent cement consisting of 3 parts of Canada balsam to 2 parts of marine glue which have been heated together in a drying oven at a temperature of about 105° C. for a sufficiently long time to make a quickly setting, strong, but not brittle cement. This cement is warmed until it is completely liquid and the specimen, wiped free of any excess paraffin, is placed in it and pressed down in such a way as to exclude all air bubbles.

The grinding of the section is continued by first grinding the specimen down as far as possible in the same manner as the first grinding was done and then finishing it on the hone. Considerable care must be exercised in doing the fine grinding, especially when the section becomes very thin, to avoid breaking it up, and frequent examinations should be made with the microscope to test its condition. All powder must be removed from the specimen by washing before it is rubbed on the hone. If the section is to be studied in oblique illumination the dry specimen should be polished on a dry hone by drawing it over the hone in one direction only.

By means of thin sections prepared as described above photomicrographs may be made with a magnification of 2000 diameters. A detailed study can be made of the internal structure of the coal and such a study throws a great deal of light on the composition and origin of coals. Thiessen has made use of this in a very practical way in the study of the occurrence of sulphur in coal and in the cor-

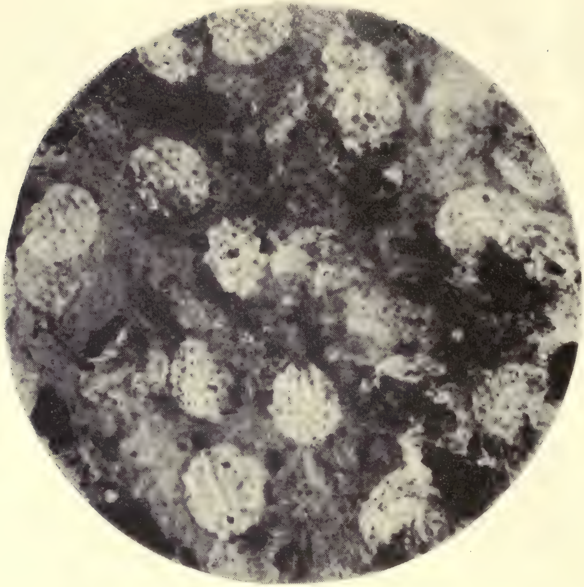


FIG. 1. Photomicrograph of horizontal section of coal from the Pittsburgh seam showing numerous spores (x 800). (Photo by R. Thiessen.)

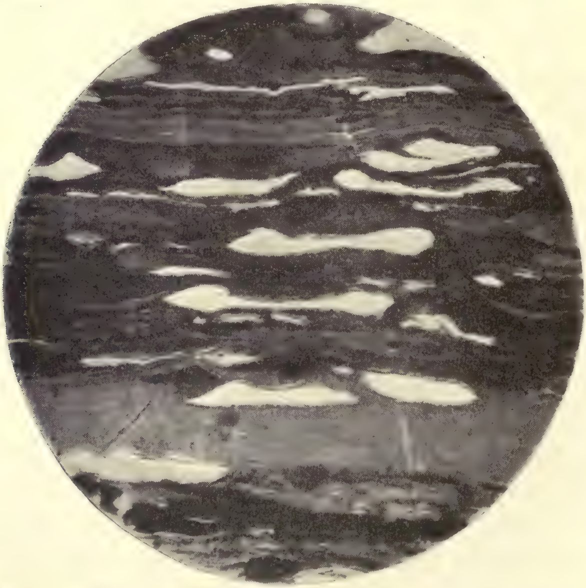


FIG. 2. Photomicrograph of a section from the coal in the Black Creek seam (x 800). It shows flattened spores peculiar to this seam. (Photo by R. Thiessen.)

relation of coal seams. It has been found that most coal seams carry certain plant spores which are characteristic of those seams and which distinguish them from other seams, just as animal fossils distinguish one formation from another in a sedimentary series (Plate II). While certain spores may be common to several seams there are usually one or more types found only in one seam. The microscope has also been of the greatest service in determining the origin and character of boghead coals and oil shales.

CHAPTER II

THE CHEMICAL PROPERTIES OF COAL

Introduction

The chemistry of coal and its derivatives is a subject of extreme complexity and of very comprehensive range. It cannot be treated fully in a text of this sort but the main principles of the subject are here set forth.

Since coal has been derived chiefly from woody constituents it consists mainly of the elements which go to compose wood, but it differs from wood in composition inasmuch as certain proportions of those elements have been changed during the fermentation and metamorphic processes which have altered the wood to coal. There have been additions to the woody matter during the growth of the vegetation, through streams and winds carrying particles of mineral matter into the coal swamps. Again, after the woody matter has changed to peat and even to the higher grades of coal, percolating meteoric waters or hot magmatic waters, the latter rising in regions where igneous rocks occur, may add a quota of their dissolved salts to the coal and increase the ash and sulphur content. In some regions of igneous activity a great variety of mineral compounds, some comparatively rare, have been found in the coals. Besides the vegetal and mineral matter a certain amount of animal matter may have been imprisoned in the coal and this may have caused a variation in some constituents, especially in the nitrogen and phosphorous content. Fish remains have been found in the rocks associated with coal seams in many localities, a notable example being that of the coal basin at Commentry, central France. Fish remains have been found also in some seams of cannel coal in England.

Constituents of Vegetation

Cellulose and lignocellulose. — The chief constituent of vegetation which goes to form coal is cellulose, the formula of which is $(C_6H_{10}O_5)$. Many writers have discussed the derivation of coal from woody materials as if cellulose were practically the only important constituent

of the vegetal matter but Clarke[1] considers that wood consists more nearly of equal proportions of cellulose and lignocellulose ($C_{12}H_{18}O_9$). The latter is known also as lignone and lignin and its composition is similar to that of jute fiber. From the formulae of these two compounds their percentage composition is as follows:

Cellulose		*Lignocellulose*	
C	44.44 per cent	C	47.06 per cent
H	6.18 "	H	5.89 "
O	49.38	O	47.05 "

If the composition of these substances be compared with that of wood it is seen that the wood runs higher in carbon, averages about

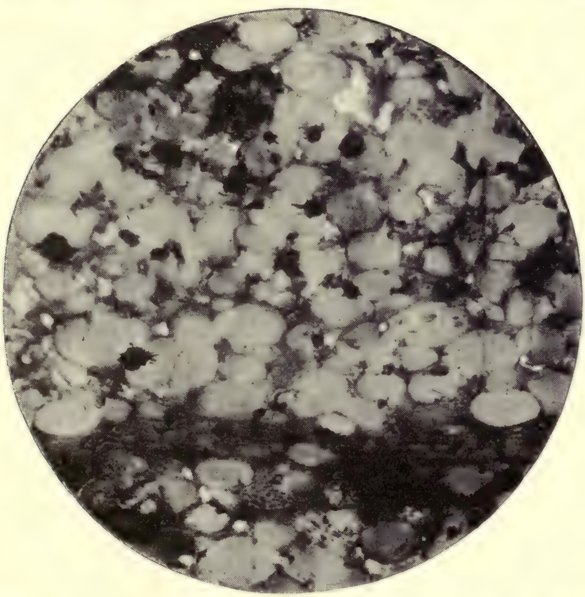


FIG. 4. Photomicrograph of section of bituminous coal from No. 5 seam, Vandalia, Indiana (x 160). Consists chiefly of particles of resin. (Photo by R. Thiessen.)

the same in hydrogen, and is considerably lower in oxygen. A fair average composition for wood is C; 49.50, H; 6.25, and O; 44.00 per cent. It will vary somewhat with the inclusion or exclusion of the oils, waxes, and gums because they are much higher in carbon and hydrogen and lower in oxygen than cellulose and lignocellulose.

[1] Clarke, F. W., The data of geochemistry. U. S. Geol. Survey, Bull. 616, 3d ed., p. 739, 1916.

Resins, fats and oils. — According to Thiessen[1] the coniferous resins, resinoles, or resinolic acids contain C; 76.8 to 83.63, H; 9.7 to 12.9, and O; 0.0 to 11.11 per cent. The waxes contain C; 80.32 to 81.6, H; 13.07 to 14.1 and O; 4.5 to 6.61 per cent. The fats and oils are composed of C; 74 to 78, H; 10.26 to 13.36, and O; 9.43 to 15.71 per cent.

Salts of organic acids. — There have also been found in lignites salts of organic acids such as whewellite, calcium oxalate, humboldtine, ferrous oxalate, and mellite, the latter a salt of aluminum and mellitic acid. Clarke[2] considers that since oxalic acid is readily formed from cellulose, and calcium oxalate is insoluble it is remarkable that the oxalate is not more common in coal.

Humus acids. — Humic acid occurs abundantly in peat and to a considerable extent in lignite. The analyses of Borntrager[3] show that in the black humus varieties of some German peats there are 12.50 to 30.00 per cent of humus acids to about 50 per cent of fiber. In the brown coal at Falkenau, Bohemia, Von John[4] has found native humic acid as a black crumbling coaly mass. It is soluble in ammonia and sodium carbonate, and hydrochloric acid precipitates all of the organic material from solution. The percentage composition is C, 54.98; H, 4.64; O, 39.98; and ash, 0.40; dried at 100°. The calculated formula is $C_{46}H_{46}O_{25}$ and it resembles somewhat a substance found in the brown coal of Bavaria. The "paper coals" of Russia also contain humic acid in considerable quantity.

The paraffin series. — The presence of at least one of the lower gaseous members of the paraffin series in coal has long been recognized because methane (CH_4) or marsh gas is a well-known gas in mines. Chamberlin[5] has also found ethane (C_2H_6) to be present in much smaller quantities. It is found in pulverizing the coal. The presence of some of the higher members of the series as liquids and solids has been pointed out by Thiessen who mentions the compounds ($C_{17}H_{36}$), ($C_{24}H_{50}$), and ($C_{26}H_{54}$) discovered by Krafft in brown coal.

[1] White, D., and Thiessen, R., The origin of coal. U. S. Geol. Survey, Bull. 38, p. 293, 1913.

[2] Op. cit., p. 741.

[3] Quoted by Clarke, Op. cit., p. 744.

[4] Von John, C., Verhandl. K. k. Reichsanstalt, p. 64, Feb. 3, 1891.

[5] Chamberlin, R. T., Notes on explosive mine gases and dusts. U. S. Bur. of Mines, Bull. 26, 1911.

Paraffins with formulae ($C_{10}H_{22}$) and ($C_{32}H_{66}$) have been described by Cohen and Finn[1] as occurring in the roof of a Yorkshire coal seam. Hall[2] separated the oils ($C_{11}H_{24}$) and ($C_{13}H_{28}$) from material taken from the roof of a coal seam in North Staffordshire, and Bedson[3] found paraffins in the Whitehaven Collieries, whose formulae were believed to vary from ($C_{13}H_{28}$) to ($C_{18}H_{38}$). It is probable that members of the paraffin series are much more common in coal than they were formerly believed to be but they are likely to be overlooked and not separated in analyses. Jones and Wheeler[4] have found solid paraffins apparently existing free in several British coals by treating the extract obtained by the solvent action of pyridine and chloroform with pentane. This solution yields crystals of paraffin wax melting between 55° and 59° C. and similar in composition to those obtained by the destructive distillation of the coal. The wax forms about 0.10 per cent of the total weight of the coals examined but it may not be present in all coals. It is the opinion of these writers that the paraffins exist as alkyl or paraffinoid groups attached chemically to another non-alkyl group, R. H. The paraffin would thus be in a so-called " bound" condition and would occur as a component part of a molecule whose general formula would be represented by $RH - C_nH_{2n+1}$ where n may have any value up to at least 32. When coal is decomposed thermally the "free" paraffins are rapidly distilled from the "bound" molecules according to the following system:

$$R\,H.C_nH_{2n+1} \rightarrow R + C_nH_{2n+2} \qquad \text{or}$$
$$R\,H.C_nH_{2n+1} \rightarrow R + C_nH_{2n+2} + C_{n_1}H_{2n_1}$$

In somewhat the same way the formation of free naphthenes is explained.

[1] Cohen, J. B., and Finn, C. P., Paraffin from Yorkshire coal seams. Jour. Soc. Chem. Ind., Vol. 31, p. 12, 1915.

[2] Hall, A. A., Oil from the roof of the Cockshead coal seam, North Staffordshire. Jour. Soc. Chem. Ind., Vol. 26, p. 1223, 1907.

[3] Bedson, P. P., Paraffin wax from the Ladysmith Pit. Jour. Soc. Chem. Ind., Vol. 26, p. 1224, 1907.

[4] Jones, D. T., and Wheeler, R. V., The composition of coal. Trans. Chem. Soc., Vol. 105, p. 140, 1914.

Gases in Coal

Gases given off at normal temperatures. — In many coal mines methane, CH_4, (marsh gas or, when mixed with air, fire damp) and carbon dioxide, CO_2, (choke damp or black damp) are found in large quantities. Carbon monoxide, CO, (white damp) occurs in lesser amounts than the other two but it is present in small proportions in many mines. The quantity of gas, consisting chiefly of carbon dioxide and methane, which escapes from some mines is very great, running into many thousands of cubic feet. What is regarded as the most gaseous mine in the anthracite region of Pennsylvania has emitted as high as 2400 cubic feet of methane per minute.

Experiments have shown that coals will absorb gases in much the same way as charcoal but regarding the actual condition of the gas in the coal before mining there is still much uncertainty. Some investigators have considered it as occluded but as Porter and Ovitz[1] have pointed out it is doubtful whether the gas exists as occluded gas, or in a condensed condition, in the true sense of the term occluded. The experiments of Chamberlin[2] and others have shown that the coal gives up a considerable quantity of methane and some ethane when pulverized but only a small percentage of that given off if the coal be allowed to stand at atmospheric temperature for several months in vacuo in a closed vessel. Porter and Ovitz have shown that although the escape of methane from a mine seems to be dependent to some extent upon the atmospheric pressure, the gas from broken coal after a time escapes at approximately the same rate under atmospheric pressure as in vacuo. The proportion of oxygen in the gas surrounding the coal does, however, have a great influence on the rate and amount of the methane given off without causing a marked effect upon the proportion of carbon dioxide set free.

From a practical standpoint these conclusions are important because ventilating a mine carries off the gas set free but it also furnishes more oxygen to the coal and thus facilitates the escape of

[1] Porter, H. C., and Ovitz, F. K., The escape of gas from coal. U. S. Bur. of Mines, Tech. Paper 2, 1911. Also Parr S. W., and Barker, P., The occluded gases in coal. University of Ill., Bull. No. 20, Vol. VI, 1909.

[2] Chamberlin, R. T., Notes on explosive mine gases and dusts with special reference to the explosions in the Monongala, Darr and Naomi coal mines. U. S. Geol. Survey, Bull. 383, 1909.

deleterious gases. The amount of gas, both methane and carbon dioxide, given off from coal which has been mined varies greatly with different coals, but in practically all cases the proportion given off during the first few days is much greater than that which escapes with an increase in the length of time during which the experiment is continued. The loss of gas is usually complete in from three to eighteen months and the deterioration in heating value is small. When coal absorbs methane it gives up nitrogen somewhat less in amount than the volume of methane absorbed[1].

Gases evolved from coal heated below temperature of decomposition. — In addition to the gases given off in the coal seams at atmospheric temperature and pressure considerable quantities are driven out of the coal by heating it to a point a little below the temperature at which decomposition begins. In view of the effect of the absorption of oxygen on the gases given off it seems probable that the increase of temperature not only expels the gas because of increasing the volume but that it aids chemical action to a slight degree. In peat the gases given off seem to consist chiefly of nitrogen and marsh gas with smaller amounts of carbon dioxide. The presence of the nitrogen is probably largely the result of air being imprisoned in the fuel. The oxygen of the air is taken up by carbon or hydrogen during the chemical processes accompanying the decay of the vegetation, leaving the nitrogen free in the peat.

The gases from lignite, heated to 100° C. in vacuo, consist, so far as they have been tested, chiefly of carbon dioxide with small amounts of carbon monoxide, nitrogen, oxygen, olefines, and marsh gas. From cannel coals the gases are largely methane and carbon dioxide. In a series of analyses of English and Scotch cannels Thomas[2] shows that when they are heated to 100° C. in vacuo they give from 16.8 to 421.3 c.c. of gas per 100 grams of coal and the composition of the gas varies as follows:

CO_2	6.44–84.55 per cent.	
CH_4	77.19–80.69 per cent.	Absent in three samples
C_2H_6	2.67–7.80 per cent.	Absent in two samples
C_3H_8	0.91 per cent.	Present in one sample only
C_4H_{10}	Not present	
N_2	5.96–46.06 per cent.	

[1] Katz, S. H., Absorption of methane and other gases by coal. U. S. Bur. of Mines, Tech. Paper 147, 1917. Also McConnell, W., Gases enclosed in coal and coal dust. Jour. Soc. Chem. Ind., Vol. 13, p. 25, 1894.

[2] Thomas, J. W., Jour. Chem. Soc., Vol. 30, p. 144, 1876.

A sample of Whitby jet yielded 30.2 c.c. of gas consisting of CO_2, 10.93; C_4H_{10}, 86.90; and N_2, 21.7 per cent. From these analyses it is seen that carbon dioxide is present in all, and abundant in some coals. Nitrogen is present in fairly large proportion in all these coals and is present also in jet. While these results obtained by Thomas are interesting it may be questioned whether they can be fully relied upon in view of the difficulty experienced at the present day with more modern analytical methods, in our attempts to recognize certain of these rarer gases.

The gases obtained from bituminous coal and anthracite under the conditions stated above are very variable in amount and composition. Von Meyer[1] found ethane up to 23 per cent and other undetermined hydrocarbon gases in small amounts in some Saxon and Westphalian coals. From the works of W. McConnell[2] on the coals from Newcastle and of Thomas[3] on the Welsh coals the following figures were compiled:

Volumes of gases derived from 100 grams of bituminous coal heated in vacuo at 100° C., 1.61 to 818 c.c.; from semibituminous and steam coal, 73.6 to 375.4 c.c.; and from anthracite, 555.3 to 600.6 c.c. The composition of the gases varied as follows:

	Semibituminous and steam coal	Bituminous	Anthracite
CO_2	5.04–18.90 per cent	0.72–36.42 per cent	2.62–14.72 per cent
CH_4 and other paraffins	72.51–87.30 "	0.40–88.50 "	84.18–93.13 "
O_2	0.33– 1.02 "	0.80– 9.41 "	
N_2	3.49–14.62 "	8.70–80.11 "	1.10– 4.25 "

The paraffins in the bituminous coals consisted in some cases almost entirely of methane although ethane was present in greater or lesser amount. The steam coal of Seaton Delaval gave off no hydrocarbons, the gas consisting entirely of carbon dioxide, oxygen, and nitrogen.

The above figures go to show that in anthracite the predominant gas is methane, while in the lower types of coal carbon dioxide, nitro-

[1] Quoted by F. W. Clarke, Op. cit., p. 759.

[2] Op. cit.

[3] Thomas, J. W., Jour. Chem. Soc., Vol. 28, p. 793, 1876.

gen and methane form the main constituents of the gas. This is further illustrated by the fact that if heated to higher temperatures but still below the point of decomposition the relative proportion of methane increases while that of nitrogen decreases. The longer the coal is heated the more gas is given off, this being especially true of hard compact coals such as anthracites. The bulk of the gas, however, is evolved early in the experiment.

Relation of mine gases to volatile constituents in coal. — The proportion of volatile matter in coal seems to have little or no relation to the percentage of gas evolved on heating below the temperature of decomposition and the explosibility of mine gases and dusts seems to depend much more upon the nature of the gases evolved than upon the relative percentage of volatile matter in the coal.

Analyses made by Thomas of the gases from blowers in coal seams and of those gases obtained from the seam by boring show that there is little difference between them. In some blowers the oxygen reaches over 10 per cent and nitrogen over 41 per cent of the gas, but oxygen is lacking in many. Carbon dioxide is less than 1 per cent in nearly all, while marsh gas constitutes over 90 per cent of the gases derived from practically all blowers and borings in the seams.

Products o Distillation

The chief products resulting from the distillation of coal are coke, tar, light oils, water of decomposition, and a mixture of gases consisting chiefly of NH_3, H_2S, H, CO_2, CO, unsaturated hydrocarbons, and C_nH_{2n+2}. The processes of distillation and the chemistry of the resulting products are subjects which are so complex that a detailed discussion of them involves a treatment of the subjects of gas manufacture, the dye industry, and many other related problems. (Fig. 5)[1].

The relative proportions of the volatile constituents obtained depend upon many factors, such as the kind of coal and the conditions under which the coal is heated, including the temperature, the pressure and the length of time involved. It has also been found that

[1] For detailed descriptions of experiments and conclusions regarding the volatile matter in coal, see Porter, H. C., and Ovitz, F. K., The volatile matter of coal. U. S. Bur. of Mines, Bull. 1, 1910; and The primary volatile products of the carbonization of coal. Tech. Paper 140, 1916. Also Rittman, W. F., and Whitaker, M. C., A bibliography of the chemistry of gas manufacture. U. S. Bur. of Mines, Tech. Paper 120, 1915.

a wet coal will produce a greater ammonia yield and less gas, but a gas richer in hydrocarbons, than a dry coal.

Effect of temperature on quantity and kind of constituents evolved. — The experiments of Porter and Ovitz have shown that, as a rule, more than two-thirds of the organic substances are decomposed at temperatures below 500° C. It is probable that some change takes place in exposed coal at atmospheric temperatures but appreciable quantities of volatile matter are given off from most coals at 250° C. In a series of experiments on bituminous coals Burgess and Wheeler[1] found that occluded or "condensed" gases which are unextractable at atmospheric temperatures are extracted in vacuo by heating from 150° to 200° C. These gases consist mainly of the higher members of the paraffin hydrocarbons. The following table shows the quantity of gas and its composition evolved from 100 grams of coal heated to 100° C. and the same amount heated to 200° C.

Temperature	Volume of gas	Composition per cent						
		CO_2	O_2	C_2H_4	$CH_{2n(n72)}$	CO	H_2	C_nH_{2n+2}
100°	34 c.c.	6.70	1.65	0.85	1.30	1.40	1.90	84.55
200°	65.5 c.c.	8.85	0.70	0.85	2.90	2.60	2.75	81.00

Of the gas obtained at 200° about 7.5 per cent consisted of butane. The identification of this gas has, however, been called in question by some chemists.

The younger coals of the western and middle-western states break down more quickly, as a rule, than the Appalachian coals. This greater ease of disintegration is probably related to the proportions of resinous and cellulosic constituents, the older coals yielding a larger proportion of hydrocarbon constituents from the resinous materials and the less mature coals a greater proportion of carbon dioxide and water. The early products of distillation are mostly CO_2, CO, and H_2O and these come off slowly up to 450° C. At this temperature the products of the lower grades of coal are mostly water and carbon dioxide, and those from bituminous coal largely members

[1] Burgess, M. J., and Wheeler, R. V., The distillation of coal in a vacuum; Trans. Chem. Soc., Vol. 105.

of the paraffin series, with gases of the series C_nH_{2n+2}, higher than CH_4, predominating below 400° C. Water of decomposition is expelled much more rapidly between 250° C. and 500° C. than at a higher temperature.

Sulphurous gases, such as H_2S, begin to be formed at 250° C. and the production rises to a climax more rapidly than that of hydrogen or the hydrocarbons. The thermal decomposition of the volatile matter takes place very readily at temperatures above 750° C. and the percentage of hydrogen and the hydrocarbons increases, with hydrogen predominating, at the higher temperatures. The increase of these gases takes place, however, at the expense of the tar, which has been increased 13 per cent in yield from Pittsburgh coal by heating it below 500° C. rather than at the usual temperature employed in carbonizing coal. It is evident that the composition of the tar obtained at the different temperatures will vary considerably. At 900° C. the volatile matter is practically all expelled from a coal of the Pittsburgh type although heated only a few seconds, which is the time necessary to raise the temperature to that point.

The experiments of Burgess and Wheeler[1] in England produced results for low temperature distillation gases, very similar to those described above, but these authors concluded that there is a decomposition point between 700° and 800° C. at which hydrogen is distilled at a marked increase in rate. This change is considered as indicating the presence in the coal of two types of compounds, one type decomposing at a lower temperature than the other and yielding mostly hydrocarbons in contrast to the other which yields hydrogen as the chief decomposition product. Although Porter and Ovitz found that hydrogen was given off in greater proportions above 750° C. they do not consider that any line of demarcation may be drawn near this point which would indicate the decomposition of distinct compounds.

[1] Burgess, M. J., and Wheeler, R. V., The volatile constituents of coal. Jour. Chem. Soc., Vol. 97, p. 1917, 1910; Vol. 99, p. 649, 1911. Clark, A. H., and Wheeler, R. V., The volatile constituents of coal. Jour. Chem. Soc., Vol. 103, p. 1704, 1913.

By-product tests on coals:

TABLE SHOWING RESULTS OF BY-PRODUCT TESTS ON VARIOUS COALS[1]

Number of Samples	16	3	23	11	11 (Air-dried)	25	46
Number of tests averaged....	2	6	2	4	2	2	2
Coke, per cent...	79.1	71.4	63.1	44.7	53.0	58.6	63.9
Tar, per cent....	7.2	11.3	11.9	7.1	5.5	12.3	10.3
Water, per cent .	1.3	4.9	10.7	27.5	19.0	11.8	10.0
Ammonia, pounds of sulphate per ton...........	12.9	23.8	25.3	27.2	26.7	26.3	26.3
CO_2, per cent....	0.44	0.72	1.20	8.14	8.41	3.13	2.13
H_2S, per cent....	0.07	0.25	0.46	0.08	0.11	0.24	0.30
Gas, cu. ft. per ton (*a*)........	9,700	8,140	8,400	7,830	8,170	7,620	7,940
Composition of gas (*b*)........							
Illuminants	1.4	3.2	3.0	2.2	2.6	5.7	5.5
CO..............	3.2	5.1	7.4	19.5	21.4	14.9	12.3
CH_4, C_2H_6, etc...	26.4	27.8	26.3(*c*)	18.1	22.6(*c*)	27.2	25.4
H..............	67.8	61.0	56.8(*c*)	54.0	49.3(*c*)	47.8	53.1
N..............	1.2	2.9	6.5	6.2	4.1	4.4	3.7
Value of "*n*" in C_nH_{2n+2}.......	(*c*)	1.27	(*c*)	1.18	(*c*)	1.32	1.29
Total volatile products without moisture...	19.7	27.4	29.8	33.3	35.5	38.5	32.4
Water of constitution.........	0.1	3.7	3.6	5.5	7.5	8.9	6.3
Inert volatile matter (*d*).....	0.7	4.7	5.1	14.0	16.3	12.4	8.8

(*a*) Calculated to dry basis at 0° C. and 760 mm. pressure, free of air and carbon dioxide. (*b*) Calculated to carbon dioxide and oxygen-free basis. (*c*) Hydrogen not determined separately by palladium but calculated from combustion: Methane probably high and hydrogen low. (*d*) Sum of carbon dioxide, ammonia and water of constitution.

The coals used in these tests were as follows: No. 16, Pocahontas; No. 3, Connellsville; No. 23, Harrisburg, Ill.; No. 11, Sheridan, Wyoming subbituminous coal; No. 25, Utah bituminous coal; No. 46, Wyoming bituminous coal.

Burgess and Wheeler[2] distilled anthracite at 900° C. for varying

[1] Porter and Ovitz, U. S. Bur. of Mines, Bull. I, p. 26, 1910. See also Church, S. R., Methods for testing coal tar and refined tars, oils, and pitches derived therefrom. Jour. Ind. and Eng. Chem., Vol. 3 p., 227, 1911.

[2] Burgess, M. J., and Wheeler, R. V., The volatile constituents of coal, Pt. II, Trans. Chem. Soc., Vol. 99, pp. 665–6, 1910.

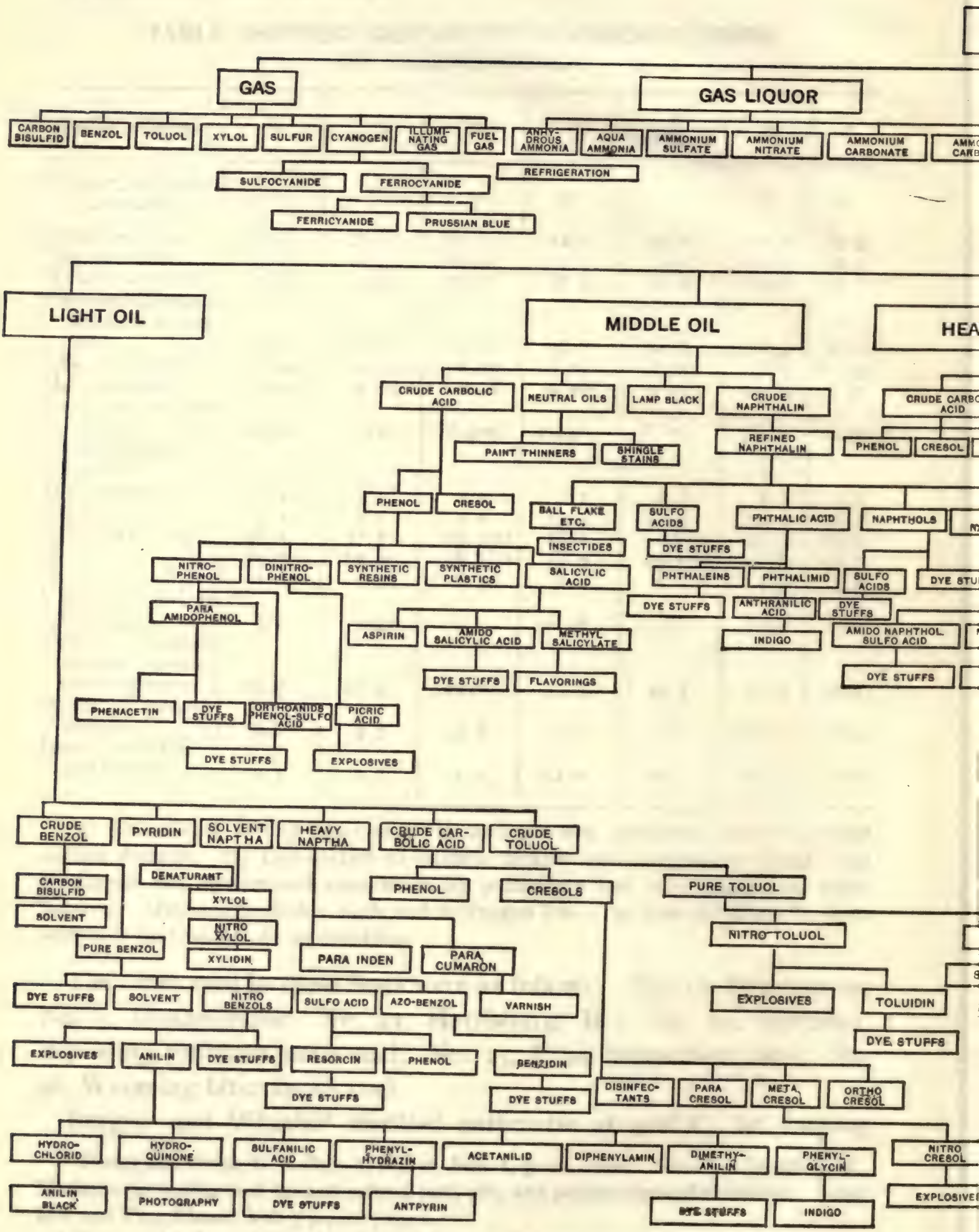
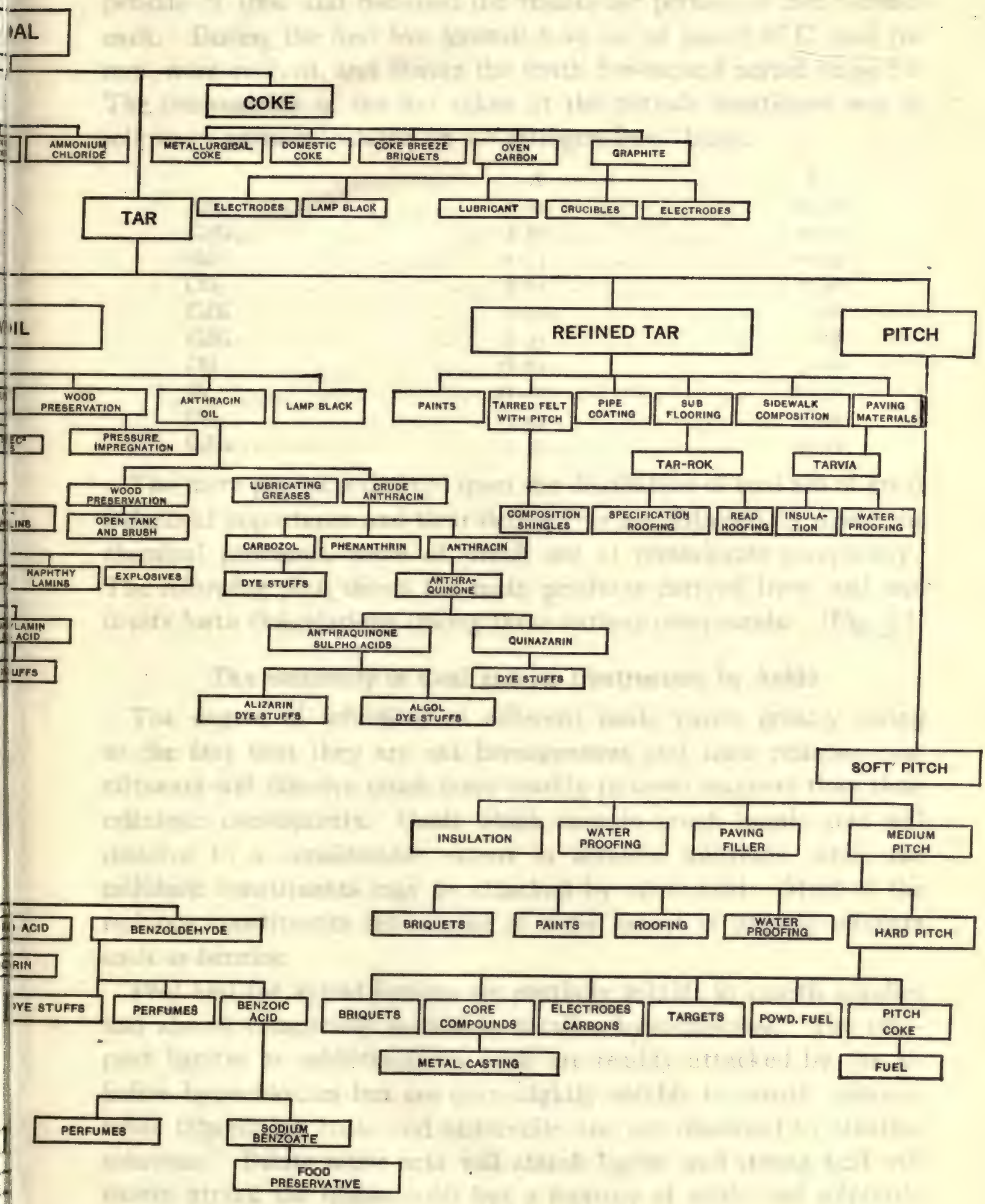


FIG. 5 Distillation products of coal and their commerci



es. (Reproduced by permission of the Barrett Company.)

periods of time and recorded the results for periods of five seconds each. During the first five seconds 6.65 c.c. of gas at 0° C. and 760 mm. were evolved, and during the tenth five-second period 20.95 c.c. The composition of the gas taken at the periods mentioned was as follows — when calculated on a "nitrogen-free" basis:

	A	*B*
NH_3	6.10	0.20
C_6H_6	3.80	0.35
H_2S	2.75	0.35
CO_2	9.85	1.40
C_2H_2	0.30	nil
C_2H_4	2.35	nil
CO	16.65	5.60
H_2	31.20	82.30
CH_4	25.95	8.40
C_2H_6	1.10	1.35

The tarry products derived from the distillation of coal are of great industrial importance and their derivatives are obtained by numerous chemical processes, some of which are of remarkable complexity.[1] The following plan shows the main products derived from coal and it sets forth the relations among these various compounds. (Fig. 5.)

The Solubility of Coal and its Destruction by Acids

The degree of solubility of different coals varies greatly owing to the fact that they are not homogeneous and their resinous constituents will dissolve much more readily in some reagents than their cellulosic constituents. Coals which contain much humic acid will dissolve to a considerable extent in alkaline solutions, while the cellulosic constituents may be attacked by nitric acid. Most of the resinous constituents are soluble to some extent in organic solvents such as benzine.

Peat and the xyloid lignites are partially soluble in caustic alkalies and almost completely soluble in alkaline hypochlorites. The compact lignites or subbituminous coals are readily attacked by the alkaline hypochlorites but are only slightly soluble in caustic alkalies, while bituminous coals and anthracite are not dissolved by alkaline solutions. Dilute nitric acid will attack lignite and strong acid will slowly attack the higher coals but a mixture of nitric and sulphuric

[1] Hoffman, A. W., Études sur les matières colorantes derivées du goudron de houille Compt. Rend., Vol. 55, pp. 781, 805, 817, 849 and 901, 1862, and Vol. 56, pp. 1033 and 1062.

acids will completely break down the more resistant coals leaving a deep brown solution from which the coloring matter is precipitated on the addition of water.[1]

By the action of nitric acid on finely pulverized coal Guignet[2] obtained oxypicric acid and a mixture of oxide of iron and sulphuric acid resulting from the pyrite in the coal. By boiling the mixture in water with barium carbonate the oxide of iron and the oxalic and sulphuric acids were thrown out while the oxypicrate of barium remained. On precipitating the barium as sulphate, crystals of oxypicric acid remained. There were left on filtering the original nitric acid solution compounds which were insoluble and which exploded when heated.

Most of the resinous compounds in coal are partially soluble in the strong acids, they are partially or entirely soluble in alcohol, and most of them partially so in ether and in turpentine. The solvent action of benzine is variable. It is thus evident that the proportion of resinous constituents in coal will affect to a considerable extent its solubility in various solvents.

Relation of solubility to coking qualities. — The results of Vignon's[3] work show that there is some definite relation between the composition of the coal, its solubility in various organic solvents and incidentally its coking quality. The coals from the Loire region showed the following results when treated with aniline. Taking fat gas coals, semi-fat coals, and lean or dry coals he obtained the following results:

	Initial weight	Weight after treatment with aniline	Percentage soluble	Percentage soluble, ash deducted
(1) Fat gas coal...	1.46–1.68	1.12–1.29	23.40	26.8
(2) Semi-fat coal..	1.17–1.32	1.09–1.23	6.58	7.2
(3) Lean or dry coal.........	2.17–2.01	2.14–2.01	1.56	1.8

[1] Fremy, E., Recherches chimiques sur les combustibles minéraux. Compt. Rend., Vol. 52, pp. 114–117, 1861.

[2] Guignet, E., Sur la constitution de la houille. Compt. Rend., Vol. 88, pp. 590–592, 1879.

[3] Vignon, Leo, Sur les dissolvants de la houille. Compt. Rend. Vol. 158, pp. 1421–1424, 1914.

The portion of the coal which is soluble is richer in hydrogen than the insoluble portion and from this it may be inferred that the coking coals will differ from non-coking coals in their solvent action with aniline.

On treating coal with alcohol, ether, benzine, toluene, aniline and nitro-benzine, Vignon obtained the following results with 50 c.c. of the solvent and 10 grams of coal.

	Soluble at ordinary temperature for 24 hours	Soluble at boiling point for 3 hours
Alcohol	0.076 per cent	0.0167 per cent
Ether	0.059 "	.....
Benzine	0.080 "	0.191 "
Toluene	0.078 "	0.190 "
Aniline	2.250 "	12.050 "
Nitro-benzine	1.410 "	3.190 "

From this table it is evident that aniline is the most active solvent for these bituminous coals of the Loire basin. Of the other common solvents pyridine and phenol may be regarded as the most active. Clark and Wheeler[1] claim that a coal may be divided into two types of compounds recognized by their differential solvent action with pyridine and chloroform, one of these compounds being higher in hydrogen and the other in hydrocarbons.

Phenol has been employed as a solvent for coal by a number of chemists, but the first extensive experiments to determine the derivatives of the solution with phenol were carried out by Parr and Hadley[2] and by Frazer and Hoffman.[3] The latter authors found that 10.87 per cent of an Illinois non-coking, bituminous coal was dissolved in phenol. From this solution a large number of derivatives were extracted, some of which are believed to be pure compounds. Parr and Hadley found that there is a distinct relation between the percentage of the coal dissolved in phenol and its coking qualities. The coking constituents are almost all dissolved in this solvent and oxi-

[1] Clark, A. H., and Wheeler, R. V., Op. cit.

[2] Parr, S. W., and Hadley, H. F., The analysis of coal with phenol as a solvent, University of Ill., Bull No. 10, Vol. XII.

[3] Frazer, J. C. W., and Hoffman, E. J., The constituents of coal soluble in phenol. U. S. Bur. of Mines, Tech. Paper 5, 1912.

dation of the coal greatly affects its relative solubility. This solvent was also used to extract organic sulphur.

Chemical Causes of Spontaneous Combustion[1]

There has been a great deal of speculation regarding the cause of spontaneous combustion of coal and many have assigned it to the oxidation of pyrite. It is now recognized, however, that while the oxidation of pyrite and the action of the sulphuric acid on moisture in the coal may produce some heat, the fundamental cause of the heating is the oxidation of the coal itself. The sulphuric acid resulting from the oxidation of pyrite is a powerful oxidizing agent and its presence facilitates oxidation of the coal, but coal itself will oxidize rather rapidly for a time after mining. If there is a good circulation of air it will not take fire but if there is only a partial supply of air oxidation goes on and the heat is retained. As the temperature of the fuel rises the rate of oxidation is greatly accelerated and in consequence there is cumulative action progressing towards the temperature of combustion which varies from about 300° C. upward depending upon the character of the coal. According to Fayol finely powdered lignite may ignite at a temperature as low as 150° C. and gas coal at 200° C.

There is a fairly definite relation, as shown by Wheeler,[2] between the temperature of ignition of coal dust and the proportion of its resinous constituents, which are soluble in pyridine.

The oxidation process goes on in both moist and dry coals, although moisture aids the process very greatly. If the coal be completely covered with stagnant water oxidation almost ceases after a brief time but circulating water may bring in new supplies of oxygen to the coal. The finer the coal, the more rapid is the oxidation of a given surface, other things being equal. The percentage of volatile matter

[1] Parr, S. W., and Kressmann, F. W., The spontaneous combustion of coal. University of Ill., Bull. 16, 1910.

Moissan, H., Traité de chimie minérale, Vol. 2, pp. 363–364, 1905, (on spontaneous combustion).

Stansfield, E., An investigation of the coals of Canada. Vol. 6, Dept. of Mines, Canada, 1912.

Hapke, L., The causes and prevention of spontaneous combustion. Chem. Zeit. 17, p. 916, 1893.

[2] Wheeler, R. V., The volatile constituents of coal, Pt. IV: The relative inflammabilities of coal dusts. Trans. Chem. Soc., Vol. 103, p. 1715, 1913.

seems to make little difference in the spontaneous heating as all types of coal have been known to heat.[1] There are, however, no authentic cases reported where anthracite has actually taken fire in storage. The natural process of heating is often accelerated by the proximity of the coal bins to furnaces and other sources of heat and this, no doubt, explains why coal on shipboard and in other places adjacent to boilers often takes fire while in the bins.

A certain amount of loss in the heating value of coal takes place during weathering and the accompanying oxidation. This may be readily understood when the results of White's investigations are considered, since he found oxygen and ash to be of almost equal anti-calorific value.[2] Further, the loss of methane accompanies the oxidation process and the heating value of this gas amounts to a small item.

Source of Mineral Constituents

The source of many of the constituents of coal is self-evident when the composition of wood is considered. The carbon, hydrogen, oxygen, and nitrogen may all be derived directly from the wood but there are many other constituents whose source and whose condition in the coal are not so readily recognized. In addition to the nitrogen in wood, which varies from less than 1 per cent to over 3 per cent, some is supplied by animal matter and it is probable that a little is added to the coal from the air through its imprisonment in the vegetation before it becomes coal.

Sulphur. — Sulphur is a constituent of considerable economic importance in coal because it reduces the quality of coke for metallurgical purposes, it increases corrosion of boilers and in quantities of more than about 2 per cent it increases clinkering in furnaces by aiding the fusion of ash. This 2-per cent limit will vary, however, with the varying proportions of ash and sulphur present and it is probable that the iron combined with the sulphur in pyrite may aid the fusibility of the ash almost as much as the sulphur. In coking approximately one-half of the sulphur in the coal is supposed to enter the coke. This proportion will apparently vary with the proportion of

[1] Porter, H. C., and Ovitz, F. K., Deterioration and spontaneous heating of coal in storage. U. S. Bur. of Mines, Tech. Paper 16, 1912.

[2] White, D., The effect of oxygen in coal. U. S. Geol. Survey, Bull. 382, 1909.

organic and inorganic sulphur. While one molecule of the sulphur in pyrite (FeS_2) may be removed in the burning process leaving the other to enter the coke with the iron, this relation will not hold for the proportions of organic sulphur, the compounds of which are not so well known.

Sulphur occurs in varying amounts in coal, from less than 1 per cent to 10 per cent or more. It commonly amounts to between one-half of 1 per cent and 3 per cent although many of the coals of our middle-west states carry between 3 and 5 per cent. The sulphur is in two forms: *organic* and *inorganic*. The inorganic type is most familiar and it occurs in the following forms: (1) Mineral sulphides, (2) Sulphates and (3) Free sulphur.

Inorganic sulphur. — Of the sulphides iron pyrite (FeS_2, Isometric) and marcasite (FeS_2, Orthorhombic) are the most common. Chalcopyrite ($CuFeS_2$), arsenopyrite ($FeAsS$), stibnite (Sb_2S_3) and a few other sulphides have been found but they are rare except in some regions where volcanic activity has occurred. Pyrite or iron pyrites, also known as "fools' gold" is responsible for most of the "sulphur balls," "coal brasses," and "sulphur diamonds" found in coal seams although marcasite frequently occurs in sulphur balls and is mistaken for pyrite since many people do not distinguish these two minerals from each other. The sulphide occurs in largest quantities in concretions, commonly known as "sulphur balls," in lenses or bands running parallel with the coal seam or in veinlets cutting across the seam. When in sufficiently large quantities it is separated from the coal in mining and at some mines it is sold for the manufacture of sulphuric acid. In addition to the masses of pyrite which are so evident to the naked eye, Thiessen[1] has shown that in practically all coals and also in peat there are numerous grains of pyrite averaging 25 to 40 microns in diameter, distributed through the fuel (Fig. 6). These appear to be more abundant in the xyloid bands in the coal and it seems quite probable that at least part of the pyrite has been formed by combination of iron with hydrogen sulphide derived from organic sulphur. These grains of sulphide are so small that they cannot be removed from the coal by washing unless the coal has been ground to fine powder.

[1] Thiessen, R., Finely disseminated sulphur compounds in coal. Trans. Amer. Inst. Min. Met. Eng. Vol. LXIII, p. 913, 1920.

The most common sulphate known is calcium sulphate or gypsum ($CaSO_4.2H_2O$). Sulphates of iron, copper and magnesium may also occur but they are not abundant. These salts occur as a result of the action of sulphuric acid on carbonates or by the oxidation of sulphides. The sulphuric acid may result from the oxidation of iron pyrite as in the following equation: $FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4$.

Native sulphur occurs only as the result of extreme oxidation of some of the minerals mentioned above and it is rare.

FIG. 6. Photomicrograph showing finely disseminated pyrite in coal (x 155). (Photo by R. Thiessen.)

Organic sulphur. — It has for many years been recognized that a portion of the sulphur in coal must exist in some form other than the mineral sulphides and sulphates. This is shown by the fact that in some coals the sulphur does not exist in such proportions that it can be combined with the elements necessary to form these mineral compounds. Sulphur which gives every indication of being com-

bined in organic compounds in coal has been found running from 0.5 to 2 per cent, and 3 per cent is reported in one coal. Thiessen points out that there is sulphur in the proteins of practically all plants and in addition to the protein sulphur there is some non-protein sulphur in most of them. This organic sulphur by putrefaction is changed to hydrogen sulphide (H_2S) which can precipitate sulphides of the metals from their soluble salts. The plants obtain the sulphur, which they assimilate in the form of sulphates, from the weathering of sulphides in the rocks or from the products of sulphur bacteria, which oxidize hydrogen sulphide to sulphuric acid. The sulphuric acid can then form calcium, magnesium or potassium sulphates, which are assimilated by the plants. R. Dawson Hall has also called attention to the fact that many coal seams contain a larger proportion of sulphur than the rocks lying above and below them, indicating the presence of organic sulphur compounds in coal. He early suspected that some of the sulphur in pyrite had an organic origin.

Phosphorous. — Like sulphur, phosphorous is an important constituent in coal which is to be used in making coke since they both enter the coke to at least some degree. Its presence in the coal may be due to solutions formed by streams running over rocks which contain calcium phosphate in some form and these solutions then precipitating the phosphate in the swamps where the coal vegetation was laid down. It is evident, however, that a certain percentage of the phosphorous is derived directly from the vegetation which produces the coal. In a study of the origin and distribution of phosphorous in bituminous and cannel coals Carnot[1] has found that certain parts of plants, especially the spores, contain considerable phosphorous. In a series of analyses he found in the Grande Couche, a thick seam at Commentry, 0.00163 per cent of phosphorous; in the coal of Ferrières 0.01385 per cent and in anthracite 0.01467 per cent of phosphorous. In several stems of typical Coal Measure plants changed to coal he found from a trace to 0.007 per cent phosphorous. Various cannels from England and central France were found to contain considerably more of this element than the other coals, the percentage varying from a trace to 0.028. Several bogheads gave 0.019 to 0.0627 per cent.

[1] Carnot, Ad., Sur l'origine et la distribution du phosphore dans la houille et le cannel coal. Compt. Rend., Vol. 99, pp. 154–156, 1884.

For comparison the spores of several modern types of ferns related to the Carboniferous plants were analysed and they contained from 0.078 to 0.228 per cent of phosphorous compared with 0.009 to 0.010 per cent for the body of the fern. The Ceratizamia mexicana yielded 0.28857 per cent phosphorous from the pollen grains and 0.11899 per cent from the envelopes which had become fairly well separated from the pollen grains. Mineral charcoal appears to be higher in phosphorous than the coal associated with it because during the change from coal to mineral charcoal the phosphorous remained while volatile constituents were lost, thus increasing the proportion of the former.

The alkalies and chlorine. — Sodium chloride and other alkaline salts may be carried into the coal in saline solutions which have been derived from the surrounding rocks. The alkalies are derived chiefly from the feldspars and related minerals and they are set free by weathering of these minerals. The chlorine comes from plants and from igneous rocks.

Silica. — This compound enters the ash of the coal and is derived chiefly from mineral matter deposited in the swamp by wind and water both as mechanical sediment and in solution. It is, however, derived partly from such plants as the *horsetails* which may contain upwards of 12 per cent of it in their stems.

Calcium, magnesium and iron. — All three of these elements may be carried in solution as carbonates in the presence of carbon dioxide. They may also be carried as sulphates and in small amounts as chlorides. The iron in the form of sulphate or chloride on coming in contact with a soluble salt, such as a salt of calcium, would normally be thrown down as the hydrous oxide unless there were an excess of carbon dioxide present to prevent oxidation in which case iron carbonate might be precipitated instead of the oxide. The presence of so much iron carbonate or "black band" associated with the coal deposits in parts of America and England is explained by assuming that the carbon dioxide, furnished by decomposing vegetation, caused the iron to be precipitated as the carbonate (siderite) rather than as the more commonly occurring hydrous oxide.

In addition to the elements mentioned there may be found in coal ash, traces of gold, silver, zinc, lead, copper, titanium, vanadium, manganese and a vast number of other elements of no particular economic importance but of some scientific interest. Of these ele-

ments zinc has been found in wood, and manganese occurs up to 25.53 per cent as Mn_3O_4 in the ash from leaves of Norway spruce, and 41.23 per cent in the ash of the bark. Some Hawaiian pineapples show 1.15 to 2.12 per cent Mn_3O_4.[1] It is thus evident that most of the elements have been derived in part directly from the vegetation and in part from solutions carried into the swamps.

The following table[2] illustrates the composition of the ash from several types of trees and it shows that at least small percentages of most of the elements may be supplied to the coal from the vegetal matter which goes to form it. Some elements seem to be entirely lacking in the ash of the common plants, while others are extremely rare. For example, molybdenum and caesium are lacking while

ANALYSES OF ASH FROM TREES

(Dried at 105° in oven)

	Birch Leaves Per cent	Birch Stems Per cent	Oak Leaves Per cent	Oak Stems Per cent	Pine Needles Per cent	Pine Stems Per cent
SiO_2	0.050	0.030	0.222	0.024	0.170	0.014
TiO_2	Trace	N.F.	Trace	Trace	0.0001	0.001
Al_2O_3	0.24	N.F.	0.038	0.070	0.253	0.090
Fe_2O_3	0.29	0.015	0.023	0.020	0.020	0.016
MnO	0.655	0.0098	0.160	0.0393	0.0596	0.011
Cr_2O_5	N.F.	N.F.	Trace	N.F.	Trace	N.F.
V_2O_5	N.F.	N.F.	N.F.	N.F.	Trace	N.F.
MoO_2	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
CaO	1.45	0.440	1.14	1.25	0.320	0.240
BaO	0.012	0.005	0.015	0.020	0.005	0.007
SrO	0.006	0.004	0.013	0.023	0.003	0.004
MgO	0.55	0.170	0.72	0.18	0.210	0.130
K_2O	1.99	0.58	0.91	0.34	0.91	0.30
Na_2O	0.10	0.13	0.13	0.15	0.07	0.07
Li_2O	0.000047	0.00003	0.00015	0.000003	0.00006	0.0001
Rb_2O	0.001	0.0003	0.000012	0.0015	0.00015	N.F.
Cs_2O	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
P_2O_5	1.10	0.33	0.261	0.274	0.27	0.075
SO_3	0.35	0.16	0.35	0.16	0.42	0.14
Cl	0.12	0.04	0.06	0.05	0.11	0.05
H_2O	8.68	8.26	7.74	6.68	7.2	8.4
Mineral constituents by addition	5.8	4.0	4.0	2.6	2.8	1.1

[1] Kelley, W. P., Manganese in some of its relations to the growth of pineapples. Jour. Ind. & Eng. Chem., Vol. I, p. 533, 1909.

[2] Robinson, W. O., Stemkoenig, L. A., and Miller, C. F., The relation of some of the rarer elements in soils and plants. U. S. Dept. Agr., Bull. No. 600, Dec. 10, 1917.

chromium and vanadium are very rare. It is evident that the high percentage of vanadium in the ash analysis quoted below is due entirely to some external source.

An analysis of ash from coal near the town of San Raphael in the province of Mendozza, Argentina, gave the following results:[1]

Soluble in Acids	*Per cent*	*Insoluble in Acids*	*Per cent*
Vanadic acid	38.5	SiO_2	13.6
H_2SO_4	12.1	Al_2O_3	5.5
P_2O_5	0.8	Fe_2O_3	9.4
Fe_2O_3	4.1	MgO	0.9
Al_2O_3	4.0		
CaO	8.44		
K_2O	1.80		

This coal contained 0.24 per cent of vanadic acid and this constituent was no doubt injected into the coal by solutions which percolated through the seam and which may have been derived from igneous sources. Igneous rocks are the source of most of such rare constituents in coal.

[1] Mourlot, A., Analyse de la houille vanadifère. Compt. Rend., Vol. 117, pp. 546–548, 1893.

CHAPTER III

CHEMICAL ANALYSIS OF COAL

Introduction

The analyzing of coal has long been recognized as the best laboratory means of determining its commercial qualities. Much attention, therefore, has been paid by chemists, geologists, and mining men, to the various methods for obtaining samples and making analyses. To be of any real value for purposes of comparison with other coals or as a means of determining the commercial qualities of a seam the coal analysed must be selected from the mine according to some definite scheme. The uninitiated person invariably pays too little attention to sampling and he very often picks out the best appearing coal, thus deceiving not only his customers but himself regarding the quality of the coal which is to be analysed. Too much attention cannot be paid to the selection of samples which properly represent the average composition of a coal seam or a shipment of coal.

Sampling for Analysis

The importance of a standard method. — Different companies or institutions may have their own methods of sampling, but it is desirable that some uniform system be adopted for sampling coal in all countries in order that the analyses made from the samples may be available for comparative purposes. Much care has been taken to standardize methods of analysis but much less attention has been paid to standardizing methods of sampling. When a sample is selected from a seam it should be taken in such a way that it will represent the coal which will be mined. If a certain portion of the parting is included in mining, this should also be included in the sample. A standard of size for the material selected is also of importance because the manner in which the portions of the seam high in ash or low in ash break down on crushing will vary greatly. This is owing to the varying character of the material constituting bony streaks in the coal. In some places these may be sandy and in others argillaceous. An analysis of the finely powdered material

may differ distinctly from the lumpy portion, and standard crushing and screening are therefore essential. The portion of the seam selected is a factor of importance because weathered coals differ in composition, heating value, and coking qualities from the unweathered coal of the same seam owing to the effects of oxidation. The nature of the roof and floor of the seam has an important bearing on the probable weathered condition and in many places on the sulphur content. Care should be taken, therefore, to observe faulted zones and other disturbed areas. Examples are known where the coal near the outcrop is higher in sulphur than that some distance underground owing to the fact that, where the roof is fractured as a result of weathering, sulphur compounds have been carried into the coal from overlying pyrite-bearing rocks. The writer knows of one case where the decision to purchase an important property on which the coal was regarded as a high-sulphur type was based entirely on the consideration of this phenomenon and the deal turned out very successfully. In some mines there is much more sulphur in the "rolls" under the seam than in the adjacent rocks and if water works through fractures in these rolls the sulphur content may be increased in the coal adjacent to them.

After the coal is obtained from the mine, car, or stock pile, care should be taken to see that if it is not analysed at once it is kept in air-tight receptacles in order that it may not lose or gain moisture, lose gas or become oxidized. It is well known that coals lose a large amount of methane on exposure to the atmosphere and take up oxygen rapidly, especially just after removal from the seam, unless they are carefully sealed. The altitude at which a sample is exposed to the air also has a bearing on its composition since a marked change in barometric conditions will affect the rate of evaporation of moisture and the escape of gases.

United States Bureau of Mines and Geological Survey mine sampling methods. — In proceeding to sample a mine it is well to procure a map if possible, so that the location where each sample is taken may be properly fixed. The number of samples to be taken will vary a great deal with the uniformity of the coal in a seam but about four samples for a daily production of 200 tons or less, with an extra sample for each additional 200 tons mined per diem, is considered sufficient.

In taking the sample the United States Geological Survey and the Bureau of Mines[1] recommend that a space 5 feet in width be cleared of dirt and powder from top to bottom of the seam. Down the center of this cleared space a zone 1 foot wide is cut to a depth of at least 1 inch, in order to get perfectly clean coal behind that removed. A cut is then made up the center of this zone to a depth of 2 inches and a width of 6 inches or, if the coal be soft, to a depth of 3 inches and a width of 4 inches. There should thus be obtained not less than 5 to 6 pounds of coal for each foot thickness of the seam and this should include, as nearly as possible, all bony coal retained in mining operations, and it should exclude all partings discarded in mining. It is suggested that in most places partings over $\frac{3}{8}$ inch thick, and sulphur balls, or other impurities, more than 2 inches in maximum diameter and $\frac{1}{2}$ inch thick be omitted from the sample.

The sample taken as described above is collected on a collecting cloth and then screened. The lumps are broken in a mortar and all passed through a $\frac{1}{2}$-inch or $\frac{3}{8}$-inch screen. The sample is thoroughly mixed with the coarser materials evenly distributed. It is then quartered and after remixing, it is requartered, if it be still too large for convenient handling. The mixing complete, the sample is placed in a can, the top screwed on and sealed with adhesive tape. The can is carefully labeled with the name of the collector, the location, the date, and all other information which might be of service when the analysis is prepared. The government bureaus have prepared very elaborate blank forms, which are filled out and shipped with the cans.

Equipment for mine sampling. — As equipment for the special work of sampling, the following materials and tools have been suggested: A portable mortar with sides 5 inches high and having a capacity of 500 cubic inches; a pestle consisting of a steel head, 1 inch thick and 3 to 4 inches long; a good spring balance of 50 pounds capacity graduated to $\frac{1}{2}$ pound; a galvanized iron wire screen of $\frac{3}{8}$-inch mesh and provided with a wooden frame; a galvanized sheet-

[1] Holmes, J. A., The sampling of coal in the mine. U. S. Bur. of Mines Tech. Paper I, 1911; Campbell, M. R., The commercial value of coal-mine sampling. Trans. Amer. Inst. of Mng. Eng., Vol. 36, p. 341, 1906; The value of coal-mine sampling. Econ. Geol. Vol. 2, p. 48, 1907; also Parr, S. W., Chemical study of Illinois coals. Illinois Coal Mining Investigations. State Geol. Survey, Bull. 3, 1916.

iron scoop 8 inches long, 2 inches deep and $1\frac{1}{4}$ inches wide, but a trowel or shingle will serve in place of this; a stiff brush; a 20-foot waterproof measuring tape; a sampling can about 9 inches deep by 3 inches in diameter made of No. 27 galvanized iron which is crimped and soldered to make it strong and air-tight; adhesive tape; a pick; and a shovel.

Sampling wagon, car, or cargo lots. — In sampling wagon-loads, carloads, or cargo lots of coal care should be taken to collect a representative sample by choosing shovelfuls from different parts of the load or pile and including an average amount of impurities. If the coal be in coarse fragments, a larger sample should be collected than if it be finely broken. About 1000 pounds should be taken as a gross sample for carload or cargo lots and this should be increased to at least 1500 pounds if the coal contains much impurity in coarse fragments. It has been found that the analysis of a large gross sample comes closer to the average for the lot than a small one, up to a certain limit, above which there is no advantage in increasing the size of the gross sample.[1]

The 1000-pound sample may be crushed so as to pass a 1-inch screen. It is then mixed, halved, by quartering method, and passed through a $\frac{3}{4}$-inch screen. This process is continued until a 30-pound sample is obtained which will pass a $\frac{8}{16}$-inch screen. After thorough mixing and quartering a sample weighing 5 pounds is taken for analysis.

From the tests of various coals by the United States Geological Survey and Bureau of Mines it has been found that certain differences exist between the analyses of mine samples and carload lots of the same coal. These differences are due chiefly to oxidation and to the changes in the moisture and gas content while exposed to the atmosphere during transportation. The following statements apply in most cases. In lignite and lignitic coals the moisture content is greater in the car sample than in that taken in the mine and the decrease in calorific value may amount to 1.3 per cent in the moisture-free and ash-free coal. If bituminous coals have a moisture content

[1] Pope, G. S., Methods of sampling delivered coal. U. S. Bur. of Mines, Bulls. 63, 1913 and 116, 1916; Bailey, E. G., Accuracy in sampling coal. Jour. Ind. Eng. Chem., Vol. 1, p. 1612, 1909; also Parr, S. W., Purchase and sale of Illinois coal on specification. Ill. State Geol. Survey, Bull. 29, 1914. (Methods of Sampling.)

of over 5 per cent in mine samples they usually lose moisture in transit but they also lose calorific value from 0.3 to 0.8 per cent. Those with less than 5 per cent usually show a gain in moisture up to about 1.5 per cent and the change in calorific value amounts to a very small decrease.[1]

Standard method of sampling. — The Joint Committee of the American Society for Testing Materials and the American Chemical Society[2] suggests the following methods for sampling and the method described in the final report of the Committee will hereafter be known in this work as the *standard method* of sampling and analyzing coal. It is insisted that the method outlined should be used in obtaining a sample whether it is taken from a 1-ton lot or from a lot containing hundreds of tons. Also if this method is adopted in a contract the following provisions shall be agreed upon (1) Place sampling is done, (2) Approximate size of sample required when standard conditions do not apply, (3) The number of samples to be taken or the amount of coal to be represented by each sample when the standard conditions (i.e. those outlined below) do not apply.

For the determination of all constituents except that of total moisture the following regulations are observed (1) The coal is sampled as it is loaded into or unloaded from conveyances or bins. If the coal is crushed as received samples may be taken after the crushing. Samples from the surfaces of piles are not reliable. (2) For taking samples a shovel or specially designed tool capable of taking equal portions of the coal shall be used. For slack or small sizes of anthracite increments as small as 5 to 10 pounds may be taken but for run-of-mine or lump coal 10 to 30 pounds may be taken. (3) The gross sample shall be not less than 1000 pounds and the increments shall be so regularly and systematically collected that the entire quantity of coal shall be properly represented in the sample. If the fragments are small, not exceeding $\frac{3}{4}$ inch in size a sample of 500 pounds is sufficient. If there is an unusual amount of slate or other impurities or if the fragments are unusually large 1500 pounds should

[1] Campbell, M. R., Op. cit. Also Fieldner, A. C., Notes on the sampling and analysis of coal. U. S. Bur. of Mines, Tech. Paper 76, 1914. For detailed descriptions of analyses see: Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner, U. S. Bur. of Mines, Tech. Paper 8, 1913.

[2] American Society for Testing Materials, A. S. T. M. Standards, (D 21–16), 1918, p. 673.

be taken. The following table shows the relation of the sizes of the fragments of the coal to the weight of the sample taken. (4) A

TABLE A

Weight of sample to be divided. In pounds	Largest size of coal and impurities in sample before division. In inches
1000 or more	1
500	$\frac{3}{4}$
250	$\frac{1}{2}$
125	$\frac{3}{8}$
60	$\frac{1}{4}$
30	$\frac{3}{16}$ or 4-mesh screen

gross sample shall be taken for each 500 tons or less, or in larger tonnages according to agreement. (5) The gross sample shall be systematically crushed, mixed and reduced in quantity to convenient size for transmittal to the laboratory. The crushing may be done by hand or by mechanical means, but loss and addition of foreign matter must be prevented. (6) The progressive reduction of the sample to the various quantities and sizes mentioned in the table above shall be carried out in the following way: (*a*) The gross sample is reduced to 250 pounds by the alternate shovel method observing the requirements for relative sizes and weights in Table A, and dividing the coal as follows: The crushed coal is shoveled into a conical pile by placing each shovelful on top of the one previously deposited and then piling the coal in this pile in a long pile as wide as the shovel and 5 to 10 feet long. This long pile is made by spreading each shovelful out for the full width and length of the pile with alternate shovelfuls spread from opposite ends of the pile. The pile is flattened from time to time. Half of this pile is discarded by beginning at the end of the pile and taking shovelfuls side by side and one after the other along the side of the pile. These alternate shovelfuls are placed in two different piles and the operation continued until the long pile is completely encompassed and practically all the coal divided between the two piles. (*b*) The sample now reduced to about 250 pounds is quartered, observing the relations outlined in Table A. Quantities of 125 to 250 pounds are coned and re-coned while smaller samples are placed on a cloth about 6 by 8 feet and mixed by raising first one end and then the other so as to roll the coal back and forth.

By gathering the four corners of the cloth a conical pile is formed and then quartered by first flattening down the apex uniformly and carefully and then dividing the pile into quarters so that the dividing lines intersect at a point beneath the apex of the original cone. The alternate quarters are discarded and the process described above is repeated until a sample of about 30 pounds is secured. (*c*) The 30-pound sample is crushed to $\frac{3}{16}$ inch or 4-mesh size, mixed, flattened and quartered. The laboratory samples shall include all of one of the quarters or all of two opposite quarters if required and it is immediately placed in a container designed for this purpose and sealed.

For the total moisture determination a special sample of about 100 pounds weight is made up by placing in a waterproof receptacle equal parts of freshly taken increments of the standard gross sample. This sample shall be rapidly crushed and reduced mechanically or by hand to about 5 pounds. This smaller sample is at once sealed airtight in a container and sent immediately to the laboratory. The standard gross sample shall not be used in place of this special moisture sample unless equally representative results can be obtained from it.

Preparation of Laboratory Samples by Standard Method[1]

Apparatus. — (*a*) Jaw crusher for crushing coarse samples to pass a 4-mesh sieve. (*b*) Roll crusher or coffee-mill type of grinder for reducing samples to 20-mesh. This mill should be entirely enclosed and have an enclosed hopper capable of holding 10 pounds of coal. (*c*) Abbé Ball Mill, Planetary Disk Crusher, Chrome-steel bucking board or any satisfactory form of pulverizer for reducing the 20-mesh material to 60-mesh. For the ball mill the porcelain jars should be approximately 9 inches in diameter and 10 inches high. The flint pebbles should be smooth and well-rounded. (*d*) Large Riffle sampler with $\frac{1}{2}$- or $\frac{5}{8}$-inch divisions for reducing the 4-mesh sample to 10 pounds. (*e*) Small Riffle sampler with $\frac{1}{4}$- or $\frac{3}{8}$-inch division for dividing down the 20-mesh and 60-mesh material to a laboratory sample. (*f*) Eight-inch, 60-mesh sieve with cover and receiver. (*g*) Galvanized iron pans, 18 by 18 by $1\frac{1}{2}$ inches deep for air-drying wet samples. (*h*) Balance or solution scale for weighing the pans

[1] Final report on coal analysis of the Joint Committee of the American Society for Testing Materials and the American Chemical Society. Jour. Ind. and Eng. Chem., Vol. 9, No. 1, p. 100, 1917. Also American Society for Testing Materials, A. S. T. M. Standards (D 22–16), p. 679, 1918.

and samples. (Required capacity 5 kilograms and sensitive to 0.5 gram.) (*i*) Air-drying oven to be used for drying wet samples. Not absolutely necessary. (Description in Bull. No. 9, Geol. Survey of Ohio, p. 312.)

Method of sampling. — There are two methods, the choice depending upon whether coal appears wet or dry.

I. When coal appears dry the first procedure is to reduce the coal in the jaw crusher to pass a 4-mesh sieve and reduce the sample to 10 pounds weight, on the larger riffle sampler. (If crushed to pass 6-mesh the sample may be reduced to 5 pounds.) The 10-pound 4-mesh sample is ground in a roll crusher or coffee-mill to 20-mesh. From various parts of this sample, take with a spoon, without sieving, a composite 60-gram total-moisture sample which should be placed directly in a rubber-stoppered bottle.

Thoroughly mix the main portion of the sample, reduce on the smaller riffle sampler to about 120 grams and pulverize to 60-mesh by suitable grinder, disregarding loss of moisture. After passing 60-mesh the sample is mixed and reduced to 60 grams on the small riffle sampler. This final sample is transferred to a 4-oz. rubber-stoppered bottle. Moisture is determined on both the 60-mesh and 20-mesh samples. The following computation is made: The analysis of the 60-mesh coal which has become partly air-dried during sampling is computed to the dry-coal basis by dividing each result by 1 minus its content of moisture. The analysis of the coal "as received" is computed from the dry-coal analysis by multiplying by 1 minus the total moisture found in the 20-mesh sample.

II. When coal appears wet the following method is followed: The sample is spread on tared pans, weighed and air-dried at room temperature, or in the special drying oven previously mentioned, at 10° to 15° C. above room temperature. It is weighed again. This drying is continued until the loss of weight is not more than 0.1 per cent per hour. The sampling is then completed as under I for dry coal.

The following computation should be made: Correct the moisture found in the 20-mesh air-dried sample to total moisture "as received" according to the following formula.

$\frac{100 - \text{percentage of air-drying loss}}{100} \times$ (percentage of moisture in

20-mesh coal) + (percentage of air-drying loss) = (total moisture "as received"). Compute the analysis to "dry-coal" and "as received" bases as under dry coal, using for the "as received" computations the total moisture as found by the formula in place of the moisture found in the 20-mesh coal.

Precautions: Owing to the fact that freshly mined or wet coal loses moisture rapidly in the laboratory the sampling operations should be carried out as quickly as possible between the time of opening the container and the securing of the 20-mesh sample and the sample should be exposed to the air as little as possible. The accuracy of the method of preparing the laboratory samples should be frequently checked by using duplicate samples and by resampling rejected portions of samples. The ash in two samples should not differ more than the following amounts under the conditions stated: if no carbonates are present 0.4 per cent; considerable carbonates and pyrite present 0.7 per cent; coals with more than 12 per cent ash, containing considerable carbonate and pyrite 1.0 per cent.

English method. — In the English government laboratories[1] the coal is usually received in the laboratory in tins such as biscuit tins, enclosed in wooden boxes, each sample weighing 20 to 30 pounds. The sample is passed through a 1-inch sieve, mixed thoroughly, quartered and one-half returned to the tin. The other half is crushed in a small Marsden-Blake crusher and by quartering reduced to about 1 pound. It is then ground in a closely set coffee-mill and divided into two parts, one of which is placed in a stoppered bottle and sealed for future reference purposes, the other being placed in a similar bottle for analysis. The sample taken from the coffee-mill is used for tests on moisture and volatile matter but for other estimations a portion is ground to pass a 50-mesh sieve. The moisture is also determined in the latter portion but the practice of determining the volatile matter in this portion also, has been discontinued as it has been found that the results differ very little for the two samples.

The Proximate Analysis

The *proximate analysis* or the determination of *moisture, volatile matter, fixed carbon, ash* and *sulphur* is the analysis usually made for practical purposes since it is much more readily made than the ulti-

[1] Pollard, W., Memoirs of the Geol. Survey, England and Wales, p. 6, 1915.

mate analysis and it furnishes most of the data necessary for the purpose of arriving at the quality of the coal. From it the grouping of the elements in the form most closely affecting combustion can be determined.

Moisture determination by the standard method. — *Apparatus:* The apparatus recommended consists of the following articles: (1) Moisture oven so constructed as to provide a minimum air space and a uniform temperature in all parts of the chamber. The air in the oven must be renewed 2 to 4 times every minute and the air must be dried by passing it through sulphuric acid. (2) Capsules with covers which permit the determination of ash in the same sample. Those recommended are the Royal Meissen porcelain capsule No. 2, $\frac{7}{8}$ inch deep and $1\frac{3}{4}$ inches in diameter, or a fused silica capsule of similar shape with a well-fitting flat aluminum cover. Glass capsules with ground glass caps may also be used and they should be as shallow as possible consistent with convenient handling.

Method: (1) For determination of moisture in the 60-mesh sample the empty capsules are heated under the conditions at which the coal is to be dried, then covered and cooled over concentrated sulphuric acid (sp. gr. 1.84) for thirty minutes and weighed. Approximately 1 gram of the sample is dipped from the bottle with a spatula and placed in the capsules which are immediately closed and weighed.

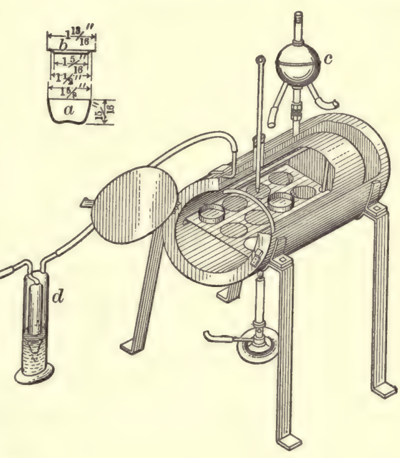


FIG. 7. — Moisture oven. (After Stanton and Fieldner, U. S. Bureau of Mines. Tech. Paper 8.)

The covers are removed and the capsules quickly placed in a preheated oven (at 104 to 110° C.) through which passes a current of air dried by concentrated sulphuric acid. The oven is closed at once and the specimens are heated for one hour. The oven is then opened, the capsules quickly covered, and cooled in a desiccator over concentrated sulphuric acid. When cool they are weighed and the moisture computed.

(2) For the determination of moisture in the 20-mesh sample 5-gram samples are used and they are weighed with an accuracy of 2 milligrams. They are heated for one and a half hours, otherwise the procedure is the same as that described above for the 60-mesh sample.

Notes: The permissible differences in duplicate determinations are as follows:

	Same analyst	Different analysts
Moisture under 5 per cent.....	0.2 per cent	0.3 per cent
Moisture over 5 per cent......	0.3 per cent	0.5 per cent

Determination of ash by the standard method. — The ash in coal or coke is a non-combustible mixture consisting of silicates of the alkalies, calcium, magnesium, iron, and titanium; oxides of iron and silicon; carbonates of iron, calcium and magnesium which may change to oxides on heating; sulphates, the most common one being that of calcium; phosphates; and arsenides. The color of the ash is often an indication of its composition, as a pure white ash generally indicates the absence of iron and a red ash its presence, although lime may counteract the color of the iron and a cream-colored ash may indicate the presence of both lime and iron. Effervescence with acid shows that carbonates are present.

Apparatus: (1) A gas or electric muffle furnace. It should have a good air circulation and be capable of maintaining a regular temperature between 700° and 750° C. (2) Porcelain capsules. Those recommended are the Royal Meissen No. 2, $\frac{7}{8}$ inch deep and $1\frac{3}{4}$ inches in diameter.

Method: The procelain capsules, containing the dried coal from the moisture determination, are placed in a cold muffle furnace or on the hearth at a low temperature and gradually heated to redness at such a rate as to avoid loss of particles of the sample from the rapid expulsion of the volatile matter. The ignition is finished when constant weight is obtained (0.001 gram) at a temperature between 700 and 750° C. The capsules are cooled in a desiccator and weighed.

Notes and precautions: The permissible differences in duplicate determinations are as follows:

	Same analyst	Different analysts
No carbonates present........	0.2 per cent	0.3 per cent
Carbonates present..........	0.3 "	0.5 "
Coal with more than 12 per cent ash containing carbonates and pyrite.............	0.5 "	1.0 "

Before the capsules are placed in the muffle for ignition to constant weight the ash should be stirred with a platinum or nichrome wire. Stirring once or twice before the first weighing hastens complete ignition.

The result obtained as above is "uncorrected" ash. The mineral matter in the ash differs materially from the actual minerals in the coal.

Other notes and methods: Some analysts have used a platinum crucible but this is not suitable for this purpose because, as stated by Carnot, if a platinum crucible which contains carbon is heated for some time a deposit of carbon and platinum dust may be made which affects the weight of the ash. A platinum crucible should never be used with coal containing pyrites. A coal high in pyrites is liable to cause more trouble if heated too rapidly than one without this mineral.

For the rapid determination of ash in coal, in the field, Lesher has designed an apparatus for the use of the geologists of the United States Geological Survey. By means of it the ash can usually be determined within 2 per cent of the figures obtained by laboratory methods.[1]

There are often considerable errors in the result obtained in the analyses of ash owing to the fact that the carbonates may change to oxides or to sulphates, depending upon certain conditions. If a carbonate changes to an oxide during combustion the carbon dioxide driven off escapes and is lost to the ash while its carbon is computed with the carbon, making it too high. This carbon is not in a combustible form and therefore does not add to the value of the coal. It will be seen that the oxygen is also affected by the error. Although these errors in the determination of ash, carbon and oxygen, are not

[1] Lesher, C. E., Field apparatus for determining ash in coal. U. S. Geol. Survey, Bull. 621-A, 1915.

considered in technical operation, where they are large they have an important bearing on correct methods of analysis and on the heating value of the coal. They have been fully discussed by a number of writers and formulae have been suggested for their correction.[1]

After the ash has been obtained from the coal, it may be analyzed in much the same way as any other inorganic mixture.

The following figures show the composition of some typical coal ashes:

	I. Per cent	II. Per cent
SiO_2	15.2–64.7	45.24–50.23
Al_2O_3	8.6–34.6	23.43–33.28
Fe_2O_3	3.8–19.0	5.50–14.68
CaO	1.0–18.1	2.76– 8.52
MgO	0.4–10.0	0.78– 2.88
K_2O	0.3– 2.9	– 3.83
Na_2O	0.1– 5.3	....
TiO_2	– 2.6	....
P_2O_5	Included with Al_2O_3	0.26– 1.85
SO_3	0.1–26.9	0.96– 3.92
Temperature of fusion		1150°–1500° C.

I. = Variations in composition shown in 9 analyses of ash from various types of coals. Quoted by Fieldner, Op. cit., p. 29.

II. = Variations in composition shown in 4 analyses quoted by Carnot, Op. cit., p. 212.

The fusibility of the ash of coal is very variable. Like that of clay it is lowered by the presence of such constituents as lime, iron, alkalies and magnesia. The temperature of fusibility is determined by use of seger cones or the pyrometer. The ash itself may be molded into a pyramid and the temperature at which the pyramid bends over to its base is considered the point of fusibility. The more readily the ash fuses the greater the difficulty arising from clinkers in the furnace. The formation of clinkers can, however, be controlled to a considerable extent by careful firing.

A list of analyses and the softening temperatures of a large number of western coals is as follows.[2]

[1] Parr, S. W., Determination of ash. Jour. Ind. and Eng. Chem., Vol. 5, p. 523, 1913. Fieldner, A. C., Op. cit., p. 27. Pollard, Op. cit., p. 40.

[2] Selvig, W. A., Lenhart, L. R., and Fieldner, A. C., Temperatures at which ash from western coals fuses to a sphere. Coal Age, Vol. 18, No. 14, p. 677, 1920.

Average for samples tested:

Alaska	2040–3010° F.	Nevada	2190–2480° F.
California	2220–2340	New Mexico	2000–3000 +
Idaho	1950–2640	Oregon	2060–2890
Montana	1930–2790	Utah	2040–2880
Washington	1870–3000 +		

Determination of phosphorous in ash by the standard method. — I. *First method:* The following method is to cover all cases: To the ash from 5 grams of coal in a platinum capsule there is added 10 c.c. of HNO_3 and 3 to 5 c.c. of HF. The liquid is evaporated and the residue fused with 3 grams of Na_2CO_3. If unburned carbon is present in the ash 0.2 grams of $NaNO_3$ is mixed with the carbonate. The melt is leached with water and the solution filtered. The residue is then ignited, fused with Na_2CO_3 alone, the melt leached and the solution filtered. The filtrates are combined, held in a flask, acidified with HNO_3 and concentrated to a volume of 100 c.c. To this solution raised to 85° C. there is added 50 c.c. of molybdate solution and the flask is shaken for ten minutes. If the precipitate does not form promptly and settle quickly, enough NH_4NO_3 is added to cause it to do so. The precipitate is washed six times or until free from acid, with a 2 per cent solution of KNO_3, then returned to the flask and titrated with standard NaOH solution. The alkali solution may be made equal to 0.00025 gram phosphorous per cubic centimeter, or 0.005 per cent for a 5-gram sample of coal and is 0.995 of one-fifth normal. Or the phosphorous in the precipitate is determined by reduction and titration of the molybdenum with permanganate.

The advantage in the use of HF in the initial attack on the ash lies in the removal of silica. Fusion with alkali carbonate is necessary for the elimination of titanium, which if present and not removed will contaminate the phospho-molybdate and is said to sometimes retard its precipitation.

II. *Second method:* Where titanium is so low as to offer no objection, the ash is decomposed in the same manner as in the first method described above, but evaporation is carried only to a volume of about 5 c.c. The solution is diluted with water to 30 c.c., boiled and filtered. If the washings are turbid they are again passed through the filter.

The residue is ignited in a platinum crucible, fused with a little

Na_2CO_3, and the melt is dissolved in HNO_3. If the solution is clear it is added to the main one but if not clear it is filtered. For the remainder of the operation this method is the same as the first method. The fusing of the residue may be omitted in routine work in a given coal if it is certain that it does not contain phosphorous.

Determination of volatile matter by standard method. — *Apparatus:* (1) Platinum crucible with tightly fitting cover and a capacity of not less than 10 c.c. nor more than 20 c.c. Dimensions to be not less than 25 nor more than 35 mm. in diameter and not less than 30 nor more than 35 mm. in height. (2) A vertical electric tube furnace, or a gas or electrically heated muffle furnace regulated to maintain a temperature of 950° C. (± 20° C.) in the crucible as indicated by a thermometer in the furnace (Fig. 8). If the determination of volatile matter is not an essential feature of the specifications under which the coal is bought a Meker burner may be used.

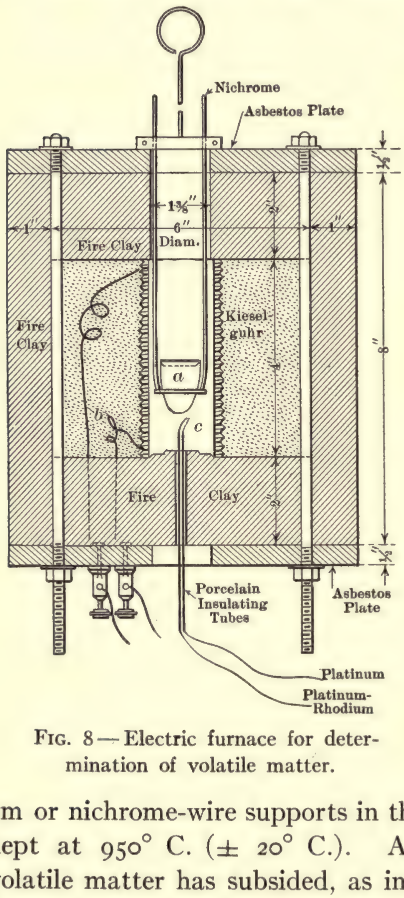


FIG. 8 — Electric furnace for determination of volatile matter.

Method: In a weighed platinum crucible of 10 to 20 c.c. capacity, closed with a capsule cover, 1 gram of coal is placed. The crucible is placed on platinum or nichrome-wire supports in the furnace chamber which must be kept at 950° C. (± 20° C.). After the more rapid discharge of volatile matter has subsided, as indicated by the dying down of the flame, the cover is gently tapped to close the crucible more tightly, and thus prevent the admission of air. The crucible is heated just seven minutes and then removed from the furnace without disturbing the lid. As soon as cool it is weighed. The loss of weight minus moisture equals the volatile matter.

For subbituminous coal, lignite or peat, a modified method is employed to avoid mechanical loss resulting from sudden heating of these coals high in volatile matter. This consists in playing a burner flame on the bottom of the crucible for five minutes thus gradually heating it to a high temperature before it is placed in the volatile-matter furnace. It is then heated in the furnace for six minutes at 950° C. as in the regular method.

Notes and precautions: The permissible differences in duplicate determinations are as follows:

	Same analyst	Different analysts
Bituminous coals	0.5 per cent	1.0 per cent
Lignites	1.0 "	2.0 "

The cover should fit close enough so that the carbon deposit from bituminous coal or lignite does not burn away from the under side of the lid. Temperatures should be carefully regulated to the standards outlined.

Other methods: According to the preliminary report of the Joint Committee[1] the method recommended was that in which the crucible of 10 c.c. capacity was heated for seven minutes over a Bunsen burner with the crucible 8 cm. above the mouth of the burner. The gas pressure required was 50 mm. and the flame about 18 cm. in height. The burner was to be surrounded with a refractory cylinder to prevent air currents from disturbing the flame. The specifications for the size of the crucible were: 2.4 cm., diameter at the base, 3.4 cm. diameter at the top and 4 cm. high. This method is still used where a suitable volatile-matter furnace is not available although a Meker burner is more reliable. When this type of burner is used the crucible is placed 2 cm. above the orifice with a flame 16 to 18 cm. high. A No. 3 Meker is the type specified. These methods are not so reliable as that with a proper furnace because of the varying conditions which it is possible to have.

Carnot's method: Carnot, a French chemist,[2] suggests using 5 grams of coal in a platinum or porcelain crucible, the size of which

[1] Jour. Ind. and Eng. Chem. Vol. 5, p. 517, 1913.

[2] Carnot, Adolphe, Traité d'analyse des substances minérales, Vol. I and II, p. 205, 1904.

will depend upon the extent to which the coal is likely to swell. The use of platinum should, however, be avoided if the coal contains pyrite, and most coals carry some of this mineral although not always in a megascopic condition. The crucible is covered with a closely fitting lid and placed in a crucible of pottery with blocks of wood charcoal surrounding it. The charcoal prevents the entrance of oxygen on cooling. The clay crucible is covered with a lid, placed in a calcination furnace, and heated for half an hour at a bright heat. It is cooled, the small crucible wiped clean and weighed. Carnot has also used a muffle furnace and, while he considers the Bunsen burner method the simpler, he thinks that the results are more liable to variation than those obtained by using a furnace.

Determination of fixed carbon by standard method. — Fixed carbon is always determined by difference as follows: 100 − (percentage moisture + percentage ash + percentage volatile matter) = fixed carbon.

Determination of sulphur by the Eschka method.[1] — While such a method as the calorimeter method may be used for purposes of control in such a laboratory as the fuel-inspection laboratory of the United States Bureau of Mines no other method is considered quite so reliable as the Eschka method although it is not so rapid as some of the others.

Apparatus: (1) Gas or electric muffle furnace, or burners for igniting the coal with the Eschka mixture and for igniting the barium sulphate. (2) Porcelain, silica or platinum crucibles or capsules for igniting coal with the Eschka mixture. (3) No. 1 Royal Meissen porcelain capsule 1 inch deep and 2 inches in diameter. This capsule presents more surface for oxidation and it is more convenient to handle than the ordinary crucible. (4) No. 1 Royal Berlin porcelain crucibles of shallow form and a platinum crucible of similar size may be used. (5) No. 0 or 00 porcelain crucibles or platinum, alundum or silica crucibles of similar size must be used for igniting the barium sulphate.

Solutions and reagents: (1) Barium chloride. — Dissolve 100 grams of barium chloride in 1000 c.c. of distilled water (2) Saturated bromine water. — Add an excess of bromine to 1000 c.c. of distilled water. (3) Eschka mixture. — Thoroughly mix 2 parts, by weight,

[1] Oesterreichische Zeitschr. XXII, p. 111, 1874.

of light calcined magnesium oxide and 1 part of anhydrous sodium carbonate. Both materials should be as nearly as possible free from sulphur. (4) Methyl orange; — Dissolve 0.02 gram in 100 c.c. of hot distilled water and then filter. (5) Hydrochloric acid. — Mix 500 c.c. of hydrochloric acid (Sp. gr. 1.20) and 500 c.c. of distilled water. (6) Normal hydrochloric acid — Dilute 80 c.c. of hydrochloric acid (Sp. gr. 1.20) to 1 liter with distilled water. (7) Sodium carbonate. — A saturated solution taking approximately 60 grams of crystallized or 22 grams of anhydrous sodium carbonate in 100 c.c. of distilled water. (8) Sodium hydroxide solution. — Dissolve 100 grams of sodium hydroxide in 1 liter of distilled water. This solution may be used in place of the sodium-carbonate solution.

Standard Method: Thoroughly mix on glazed paper 1 gram of coal and 3 grams of Eschka mixture. Transfer the mixture to a No. 1 Royal Meissen capsule, a No. 1 Royal Berlin crucible, or a platinum crucible of similar size. Cover with about 1 gram of Eschka mixture. Ignition shall be performed by heating the crucible over an alcohol, gasoline, or a natural gas flame or in a gas or electrically heated muffle. Artificial gas must not be used owing to its sulphur content, unless the crucible is heated in a muffle. When heated over a flame the crucible is placed in a slanting position on a triangle over a very low flame. This is necessary to avoid rapid expulsion of volatile matter which tends to prevent complete absorption of the products of combustion of the sulphur. The crucible is heated slowly for thirty minutes, the temperature being increased gradually and the mixture being stirred after all black particles have disappeared. The latter condition indicates the completeness of the operation.

If the crucible is heated in a muffle, it should be placed in a cold muffle and the temperature gradually raised to 870°-975° C. (cherry-red heat) in about one hour. This maximum temperature is maintained for about 1½ hours and the crucible is then allowed to cool in the muffle.

After cooling, the contents are emptied into a 200 c.c. beaker and digested with 100 c.c. of hot water for one-half to three-quarters of an hour with occasional stirring. The solution is filtered and the residue washed by decantation. After several washings insoluble matter is transferred to the filter and washed five times, the mixture being kept well agitated. The filtrate amounting to about 250 c.c. is

treated with 10 to 20 c.c. of saturated bromine water which is then made slightly acid with hydrochloric acid and boiled to expel the liberated bromine. The so ution is then made just neutral to methyl orange either with sodium hydroxide or sodium carbonate solution and 1 c.c. of normal hydrochloric acid is then added. It is boiled again and 10 c.c. of a 10 per cent-solution of barium chloride ($BaCl_2$-$2H_2O$) is added slowly from a pipette with constant stirring. The boiling is continued for fifteen minutes and the solution allowed to stand for at least two hours, or better over night, at a temperature just below boiling. It is filtered through an ashless filter paper and washed with hot distilled water until a silver nitrate solution shows no precipitate with a drop of the filtrate. The wet filter containing the precipitate of barium sulphate is placed in a weighed platinum, porcelain, silica or alundum crucible, free access of air being allowed by folding the paper over the precipitate loosely so as to prevent spattering. The paper is smoked off gradually and at no time allowed to burn with flame. After the paper is practically consumed the temperature is raised to approximately 925° C. and heated to constant weight.

The residue of magnesia, etc., after leaching should be dissolved in hydrochloric acid and very carefully tested for sulphur. If an appreciable amount is found it should be determined quantitatively as the amount of sulphur obtained is important.

Blanks and Corrections: A correction must always be applied either (1) by running a blank exactly as described above using the same amount of all reagents that were employed in the regular determination, or more surely (2) by determining a known amount of sulphate added to a solution of the reagents after these have been put through the prescribed series of operations. If the latter procedure is adopted and carried out once a week or whenever a new supply of a reagent must be used and for a series of solutions covering the range of sulphur content likely to be met with in coals, it is only necessary to add to or subtract from the weight of barium sulphate obtained from a coal, whatever deficiency or excess may have been found in the appropriate "check" in order to obtain a result that is more certain to be correct than if a "blank" correction as determined by the former procedure is applied. This is due to the fact that the solubility error for $BaSO_4$ for the amounts of sulphur in question and

the conditions of precipitation prescribed, is probably the largest one to be considered. $BaSO_4$ is soluble in acids and even in pure water and the solubility limit is reached almost immediately on contact with the solvent. Hence, in the event of using reagents of very superior quality or of exercising more than ordinary precautions there may be no apparent "blank" because the solubility limit of the solution for $BaSO_4$ has not been reached or, at any rate, not exceeded.

The Atkinson and sodium-peroxide methods give results similar to those obtained by the Eschka method. According to Register if 5 per cent of nitrogen is present in the gases contained in the bomb calorimeter, the sulphur of a coal is almost completely oxidized to H_2SO_4 and the washings of the calorimeter may be used for the determination of sulphur.

The permissible differences in duplicate determinations are as follows:

	Same analyst	Different analysts
Sulphur under 2 per cent......	0.5 per cent	0.10 per cent
Sulphur over 2 per cent......	0.10 "	0.20 "

Sulphur determined by the bomb calorimeter. — To determine the sulphur content of a coal by means of the bomb calorimeter the washings from the calorimeter are collected in a 250 c.c. beaker. The solution is titrated with standard ammonia (0.00587 gram per c.c.) to make the "acid correction" for the heating value, methyl orange being used as an indicator. To this solution is added 5 c.c. of dilute hydrochloric acid (1 : 2) and it is then raised to the boiling point before filtering off any insoluble matter. After thorough washing, the filtrate is boiled and the sulphur precipitated with barium chloride as in the Eschka method. The percentage of sulphur is then derived as follows:

$$\frac{\text{Weight of } BaSO_4 \times 13.74}{\text{Weight of sample}} = \text{percentage of sulphur.}$$

The results obtained by the calorimeter are usually 3 to 8 per cent lower than those by the Eschka method. (For a further note on this method see discussion under "The bomb calorimeter."

The calorimetric method is recommended by Parr[1] who also uses it for sulphur in coke. The coke is pulverized and burned in the Parr peroxide calorimeter with sodium peroxide and the sulphur determined in the washings.

The Photometric Method with Turbidimeter. — There are many variations of the photometric method but they can only be used for rough determinations. One apparatus which seems to give satisfactory results is a modified form of the Jackson candle turbidimeter (Fig. 9). This is one type of the turbidimeter which is being adopted by many analysts for rapid determinations of sulphur in control work. The principle of this apparatus is a brass stand, in the center of the base of which there is a holder for an English standard candle. This candle is regulated so that a flame 30 to 40 mm. long is maintained. Above this candle is a horizontal support with a hole in the center. Over this hole a graduated glass cylinder with flat polished bottom is placed in a vertical, opaque cylinder more than half the height of the glass vessel. Since this apparatus is used mainly for rapid water analysis[2] the vessel is graduated so that the lines correspond to turbidities produced in distilled water by silica when present in certain parts per million. A 25-centimeter tube may show turbidities of 100 to 5000 parts per million of silica and a 75-centimeter tube 25 to 5000 parts per million.

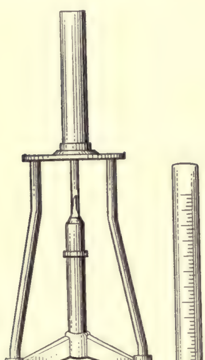


FIG. 9. — Jackson's candle turbidimeter.

The early designs of this instrument were not very satisfactory for the determination of sulphur, but after an extended series of experiments Muer[3] found that with certain revised tables quite satisfactory results could be obtained. A series of experiments by this modified method gave results which compare favorably with those obtained by the gravimetric method. The method as outlined as is follows: The washings from the bomb calorimeter amounting to about 150 c.c.

[1] Parr, S. W., Composition and character of Illinois Coals. Ill. State Geol. Survey, Bull. 3, p. 55, 1906.

[2] U. S. Geol. Survey, Water supply and irrigation paper No. 651, 1905.

[3] Muer, H. F., The determination of sulphur in coal by means of Jackson's candle turbidimeter. Jour. Ind. and Eng. Chem., Vol. 3, p. 553, 1911.

are filtered and then titrated with N/10 sodium carbonate, using methyl orange as indicator. The titrated solution is then made up to 200 c.c. The acidity of the solution may be taken as an index of the amount of solution to be taken for the sulphur test. For anthracite the proportion taken is $\frac{1}{4}$ to $\frac{1}{2}$ and for soft coals $\frac{1}{4}$ to $\frac{1}{10}$ of the whole. This portion of the solution is measured in the turbidimeter tube diluted to near the 100 c.c. mark on the tube. It is shaken, acidified with 1 c.c. of 1 : 1 hydrochloric acid and made up to the 100 c.c. mark. It is mixed thoroughly by shaking. A tablet of barium chloride, weighing 1 gram and having been compressed without the use of a binder is placed in the solution. The barium chloride in this particular form seems to give the most finely divided precipitate and therefore the best results. After the tablet is placed in the tube the latter is closed by a clean rubber stopper and then rolled gently until the precipitation of the sulphur is complete. The turbid liquid is transferred to a beaker. The candle is lighted, the graduated tube is put in place, and enough of the liquid is at once poured in to prevent the tube from cracking. The liquid is then gradually poured in, being allowed to run down the side of the tube, until the flame becomes dim as one looks down the tube. The liquid is then added very slowly until the flame just disappears. The depth of the liquid in centimeters is noted, the liquid returned to the beaker and a new reading made. This process is repeated until a good average reading is obtained. Knowing the depth of the liquid in centimeters the weight of sulphur and sulphur trioxide in milligrams may be obtained from a table which Muer has prepared. In his experiments he found that for a depth of less than 2.5 cm. of liquid there was a sharp deviation from a straight line curve in which the increase in depth in centimeters was inversely proportional to the weight of sulphur in milligrams. This variation seems to be due to the lens effect of the bottom of the tube and to avoid it the solution should be diluted so that the depth will be greater than 2.5 cm. For depths above 17.0 cm. there was also a marked variation from the straight line and to avoid this it is better to concentrate the solution. For all readings between these two limits it was found that the following formula is applicable:

$$S = 0.6 + \frac{15.3}{C}$$

where S is the weight of sulphur in milligrams and C is the depth of the liquid in centimeters at the time the flame becomes obscured.

Methods for determining the proportions of the various forms of sulphur in coal. — In a recent article Powell and Parr[1] have enumerated methods for determining the proportions of the various forms of sulphur in coal, as follows: For sulphate sulphur the coal is treated with hydrochloric acid after fine grinding. A sample of 5 grams is treated with 300 c.c. of a 3-per cent solution of the acid, for forty hours at 60° C. The solution is filtered and the filtrate analyzed for sulphur as in the regular method by precipitation with barium chloride ($BaCl_2$). For the pyrite sulphur determination the sulphate sulphur is first removed as described above with hydrochloric acid and the coal is then treated with nitric acid. A 1-gram sample of the finely powdered coal is employed and about 80 c.c. of nitric acid (1 part HNO_3 sp. gr. 1.42 to 3 parts water, resulting sp. gr. about 1.12) is used. The solution stands at room temperature for twenty-four hours before being filtered. The nitric acid is disposed of by evaporating the filtrate to dryness and after taking up with a little hydrochloric acid the sulphur is precipitated by barium chloride ($BaCl_2$).

The resinic sulphur is determined by treating the coal with phenol; this treatment involves prolonged extraction with this reagent. The other form of organic sulphur, known as the humus sulphur, is determined directly by taking the residue from the nitric acid extraction and adding 25 c.c. ammonium hydroxide (sp. gr. 0.90). This mixture is allowed to stand for several hours; it is then diluted, passed through a large filter and the filtrate evaporated to dryness. The sulphur may then be determined in the usual manner by fusing the residue with sodium peroxide. It is evident that the total organic sulphur may be determined by subtracting the sum of the sulphate and pyrite sulphur determinations from the total sulphur, or the humus sulphur might be determined by difference between total sulphur and the sum of the other three types.

Sulphur in ash. — A determination of sulphur in the ash may be made by placing the ash in an evaporating dish, adding hydrochloric acid, evaporating to dryness, then taking up with hydrochloric acid

[1] Powell, A. R., and Parr, S. W., Forms in which sulphur occurs in coal. Trans. Amer. Inst. Min. Met. Eng., Vol. LXIII. p. 674, 1920.

and hot water. This solution is filtered and, after washing, the sulphur is precipitated as barium sulphate ($BaSO_4$) by adding barium chloride ($BaCl_2$). From the result obtained the combustible sulphur in the coal may be determined by subtracting the above result from the total sulphur.[1]

Ultimate Analysis

Determination of carbon and hydrogen. — The determination of carbon and hydrogen is made with a combustion furnace, either gas or electric. The gas furnace used is usually the Glaser type with twenty-five burners. The Fletcher furnace is often used in England. The principle involved is the complete oxidation of the carbon and hydrogen by passing the products of combustion over red-hot copper oxide. The sulphur is taken up by lead chromate.

Description of the furnace: The apparatus consists of a purifying train in duplicate, a combustion tube and an absorption train (Fig. 10). The purifying train is in duplicate so that oxygen may be fed from a gas vessel, such as a Linde oxygen cylinder, through one set of tubes and air through the other. It is connected to the combustion tube by a three-way tap so that the currents may be regulated. The air and oxygen are first passed through sul-

[1] Pollard. Op. cit., p. 9.

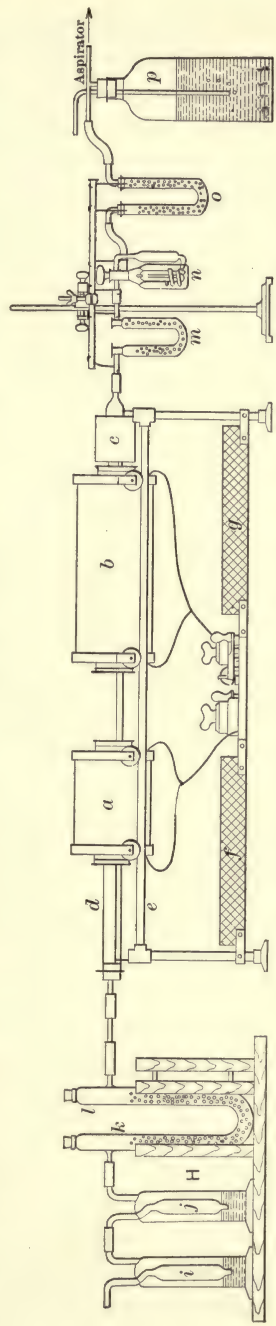


Fig. 10. — Electric combustion furnace for the determination of carbon and hydrogen.

phuric acid, then through a 30 per cent potassium hydroxide solution, then over soda lime and granular calcium chloride in a U-tube. Some English analysts use two U-tubes filled with pumice saturated with sulphuric acid, the pumice having previously been ignited with sulphuric acid to remove chlorides and other impurities, in place of the soda lime and calcium chloride tube. A small bottle of sulphuric acid may be connected in series next to the combustion tube for the purpose of indicating the rate at which the gases are being fed to the combustion tube.

The combustion tube should be from 100 to 110 cm. in length by about 21 mm. in external or 12 to 15 mm. internal diameter. It should be of hard Jena or similar glass.

The absorption train consists of a Marchand tube filled with granular calcium chloride ($CaCl_2$) for absorption of the water. Instead of this material a U-tube filled with pumice saturated with sulphuric acid may be used. If the acid be used it is well to fill the tube, allow it to stand over night and then drain off the acid just before using. Following the Marchand tube there is a Liebig or Geissler bulb filled with 30 per cent potash solution to absorb the carbon dioxide given off. This solution should be treated with a little potassium permanganate for the purpose of oxidizing any ferrous iron or nitrates. In place of this solution powdered potash is often used. A guard tube comes next and is filled with soda lime and granular calcium chloride so as to absorb any traces of carbon dioxide and moisture which have passed the other tubes. Some analysts use sulphuric acid and pumice for this purpose.

Testing the apparatus: To prepare the apparatus for a determination care should be taken to see that all the reagents used are fresh and pure. A blank test may be run by passing about a liter of air through the train, heated as in a regular test; if there is a change in weight in the absorption tubes of less than 0.5 mg. each the apparatus is considered ready for use.

Method of making the determination with furnace: The sample of dry coal ground to 50 or 60-mesh is weighed into a platinum or porcelain boat. The weight of the sample used varies with different analysts, some considering that a 0.5-gram sample is best while others use a 0.2-gram sample. The latter is recommended by the analysts of the United States Bureau of Mines. The boat containing the

sample is kept in a weighing tube to exclude moisture while preparations are being made for placing it in the combustion tube.

The combustion tube is filled in different ways by different analysts. For example, Pollard leaves a space of 10 cm. at each end of the tube. The space is followed by 6–8 cm. of copper-oxide roll; 16–20 cm. for the boat; 45 cm. of copper oxide; 8 cm. lead chromate; and 10 cm. of silver spiral. Stanton and Fieldner leave the first 30 cm. of the tube empty. This space is followed by an asbestos, acid-washed and ignited plug, or a roll of copper gauze. Following this is 40 cm. filled loosely with copper-oxide wire. The wire is separated from 10 cm. of lead chromate by another asbestos plug. A third asbestos plug 20 cm. from the end of the tube keeps the chromate in place.

The combustion tube containing the boat in which the coal is spread out flat is connected in the train and the train is connected with an aspirator which produces a steady suction. The suction may be kept constant by using a Mariotte flask. It is easier to keep the joints tight if the gases be drawn through the apparatus than if they be forced through by pressure. A satisfactory test for the tightness of the apparatus is to draw air through the potash bulb at the rate of three bubbles per second. The three-way tap is then closed and if not more than three bubbles of gas pass the potash bulb per minute it is considered satisfactory.

When the boat is placed in the combustion tube care must be taken to have the copper oxide at a bright red heat and the lead chromate at a dull red before the coal is heated. Otherwise methane may escape combustion. Before the coal is heated a current of oxygen is passed. The coal must be heated gradually; otherwise too much tarry matter may be driven off in a short space of time to permit complete combustion. The heat is increased gradually and the current of oxygen is maintained for about two minutes after the sample ceases to glow when it is turned off and about 1200 c.c. of air is drawn through the train.

The absorption bulbs or tubes are disconnected and weighed. The hydrogen percentage in a 0.2-gram sample is determined by multiplying the increase in weight in the calcium chloride tube by 55.55 and the carbon percentage by multiplying the increase in weight in the potassium hydroxide bulb by 136.36. It is evident that

the percentage of carbon will vary slightly if there are carbonates in the coal and the hydrogen will vary if there are hydrous minerals or moisture present.

The ash in this sample may be weighed and its percentage also determined. Duplicates should agree within 0.1 per cent for hydrogen and 0.2 per cent for carbon.

A convenient electric furnace of the Heraeus type may be used in place of the gas combustion furnace. This furnace as used by Stanton and Fieldner[1] consists of three independent heaters. Two of these are on wheels and mounted on a track so that they are movable. The third one is stationary around the tube where the lead chromate is located. The stationary heater is not a part of the regular Heraeus furnace but it was added by winding an alundum tube 12 cm. long with No. 16 nichrome II wire and enclosing it in a cylinder packed with magnesia-asbestos.

The movable heaters have very thin platinum foil, weighing about 9 grams in all, wound on a porcelain tube of 30 mm. internal diameter. The combustion tube is about 21 mm. external diameter and 900 mm. in length. It consists of Jena glass or fused silica. It is supported in an asbestos-lined nickel trough. Each heater has a separate rheostat and the current required is about 4.5 amperes with 220 volts.

The purifying train consists of a Tauber s drying apparatus which contains sulphuric acid, a 30 per cent potassium hydroxide solution of granular soda lime and calcium chloride. The absorption train consists of a 5-inch U-tube containing granular calcium chloride; a Vanier potash bulb containing a 30 per cent potassium hydroxide solution and granular calcium chloride; a guard tube, containing granular calcium chloride and soda lime; and a Mariotte flask for preserving a constant pressure. The calcium chloride used in the tube should be saturated with carbon dioxide before using by being placed in a large drying jar and having the jar filled with carbon dioxide. The jar is left over night and dry air is then drawn through it to remove the carbon dioxide. The saturated material may then be kept in tightly stoppered bottles.

It is possible with this furnace to so adjust the heaters that the tube may be dried carefully, the lead chromate may be kept hot and

[1] Op. cit., p. 22.

the copper oxide may be raised to a red heat before the boat containing the sample is heated to a high temperature. The boat is then heated until all the carbon is burned off as indicated by the fact that the residue ceases to glow. The tubes are then weighed and the calculation made as in the determination described above with the gas combustion furnace.

In addition to the methods described above Parr[1] has described a process for determining total carbon with the improved Parr Calorimeter.

A description of this calorimeter is as follows: *AA* (Fig. 11*a*), is a liter can for water; *BB* and *CC* are insulating vessels of indurated fiber; *D* is a cartridge to receive the charge of coal and chemicals.

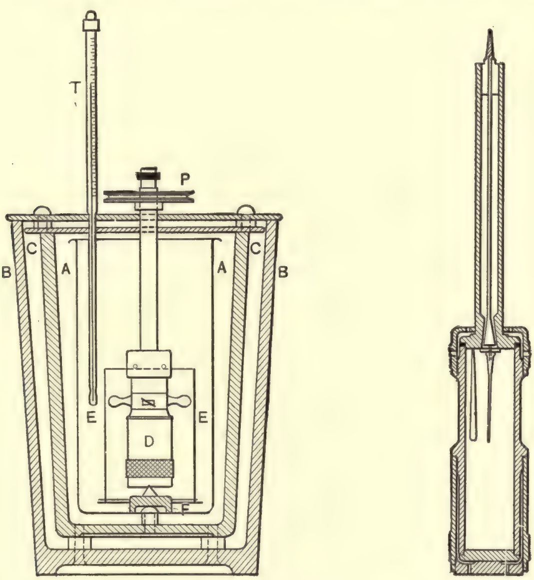


Fig. 11. — (*a*) Parr peroxide bomb calorimeter. (*b*) Bomb enlarged.

It rests on the pivot *F* and is made to revolve by means of the pulley *P*. The small turbine wings produce complete circulation of the water. The temperature is recorded on the thermometer *T*. Figure 11*b* is an enlargement of the bomb or cartridge which has been improved by placing the air chambers around the inner shell. These chambers contain air which the sudden rise in temperature expels. The air

[1] Op. cit.

at first prevents the cooling of the sides of the chamber to such a point that the chemical action around the walls is checked and then on being expelled it permits the cooler water to come into contact with the hot walls of the shell and produce a more rapid transfer of heat and consequently greater efficiency.

Parr used sodium peroxide and the reaction is approximately as follows:

$$\underset{\text{Sodium peroxide}}{56\,Na_2O_2} + \underset{\text{Coal}}{C_{25}H_{18}O_3} = \underset{\text{Sodium carbonate}}{25\,Na_2CO_3} + \underset{\text{Sodium hydrate}}{18NaOH} + \underset{\text{Sodium oxide}}{22Na_2O}.$$

For such substances as coke, petroleum, and anthracite a more vigorous oxidizing medium is used. The most effective is a mixture of potassium chlorate and nitrate in proportion of 1 to 4 and used with sodium peroxide in proportion of 1 to 10. This was used to good advantage on the slaty coals.

Parr devised this method in order that there might be some ready means of obtaining the total carbon as this was necessary in his classification of coals. He also devised a curve from which can be read the percentage of combustible or available hydrogen when the carbon content is known. The curve is based on the principle that there is a more or less definite relation in the various coals between the total carbon, the fixed carbon, and the "available" hydrogen. (For a discussion of the subject of available hydrogen in coal, see Parr's Classification in Chapter 5.)

The determination of nitrogen. — The method usually employed for the determination of nitrogen is the modified Kjeldahl-Gunning method.[1] A gram of coal is placed in a 500 c.c. Kjeldahl flask together with 30 c.c. of concentrated sulphuric acid, 5 to 8 grams of potassium sulphate (K_2SO_4) and 0.6 grams of mercury. Mercury oxide may be used instead of mercury, but a gram of the oxide is necessary. The solution should be boiled until the coal is all oxi-

[1] Dyer, B., Kjeldahl's method for the determination of nitrogen. Jour. Chem. Soc., Vol. 67, pp. 811–817, 1895. Also, Trescot, T. C., Comparison of the Kjeldahl-Gunning-Arnold method with the official Kjeldahl and official Gunning method of determining nitrogen. Jour. Ind. Eng. Chem., Vol. 5, pp. 914–915, 1913 and Wedemeyer, K., Ein Wort zur Stickstoffbestimmung nach Kjeldahl-Gunning. Chem. Ztg. Jahrg. 22, p. 21, 1898.

dized and the solution has become practically colorless. The boiling may require two hours or more, depending upon the nature of the coal. The solution is allowed to cool and a little potassium permanganate ($K\,Mn\,O_4$) is added or it may be added without cooling. Some analysts add this while the solution is hot, while others cool it first. After boiling for an hour, the permanganate is added together with more mercury and then boiled again until complete oxidation results.

The solution is cooled and diluted to about 200 c.c. with cold water. To this is added 20 to 25 c.c. of potassium sulphide (K_2S) solution (40 grams per liter) to precipitate the mercury. Sodium sulphide (Na_2S) of same strength is sometimes used in place of the potassium sulphide. A little zinc is added to prevent bumping and then about 80 to 100 c.c., or enough to make the solution alkaline, of a 50 per cent solution of sodium hydroxide (NaOH). The Kjeldahl flask is at once connected with the condenser and the ammonia is distilled over into a measured amount (usually 10 c.c.) of standard sulphuric acid, to which cochineal indicator is added for titration. The distillation is continued until about 200 c.c. has passed over. The distillate is then titrated with standard ammonia solution. (In this case 20 c.c. NH_4OH = 10 c.c. H_2SO_4 = 0.05 grams nitrogen.)

Pollard[1] states that the following modification was used in the English Government laboratory with good results, a sharper end-point being obtained by this method than in the former practice. The duplicates agreed to within 0.05 per cent. To 1 gram of coal 30 c.c. of pure, concentrated sulphuric acid containing 1 gram of salicylic acid was added. The vessel was kept cool by being immersed in water while the acid was added. To this solution 5 grams of sodium thiosulphate were carefully added and then 7 grams of potassium sulphate, followed by a crystal of copper sulphate. This mixture was heated gradually at first and then strongly until complete oxidation occurred. It was cooled, and distilled with excess of soda and a little sodium sulphide in the usual way, into 25 c.c. of N/10 sulphuric acid. The excess of soda was determined by adding to the solution 10 c.c. of a 10 per cent solution of potassium iodide, the liberated iodine being determined in the usual way. Pollard's use of copper sulphate is interesting in view of the fact that Fieldner and

[1] Op. cit., p. 9.

Taylor[1] found that copper sulphate was not as good a catalytic agent as mercury.

The determination of oxygen. — A great many different analytical methods have been suggested for the determination of oxygen but none of them are sufficiently simple or accurate to be generally accepted.[2] The scheme almost universally adopted is to obtain oxygen by difference, the sum of carbon, hydrogen, nitrogen, sulphur, and ash being subtracted from 100 per cent. This has one great disadvantage because it throws upon the oxygen the accumulated errors in the determination of carbon, hydrogen, nitrogen, sulphur and ash. These errors may tend to balance one another to some extent but there are many indefinite factors which may affect the result. If the coal contains iron pyrite this tends to make the oxygen too low; if it contains argillaceous materials, which would naturally carry water of composition, the oxygen in the coal will be too high.[3] Carbonates from the coal, as already pointed out, will have a bearing on the proportions of oxygen and carbon in the coal. This is because there is no means, with our present methods, of distinguishing between the carbon and oxygen from the coal and that from the carbonates unless an analysis of the ash be made and the various constituents computed in terms of carbonates, sulphides, etc., an operation which cannot be carried out in practice.

Some of the methods used for the direct determination of oxygen in coal are based on the following principles: Baumhauer[4] endeavored to reoxidize the copper reduced in the combustion tube. He also employed iodate of silver. Mitscherlich[5] has used at different times a current of chlorine which united with hydrogen to form hydrochloric acid, leaving the oxygen free or to unite with carbon, and mercury dioxide. Since a certain amount of oxygen must be supplied in addition to that in the coal in order to produce complete

[1] Fieldner, A. C., and Taylor, C. A., Determination of nitrogen in coal. U. S. Bur. of Mines, Tech. Paper 64, p. 22, 1915.

[2] For a good summary of various methods see Carnot, Op. cit., p. 229.

[3] Parr, S. W., An initial coal substance having a constant heating value. Ill. State Geol. Survey, Bull. 8, 1907.

[4] Baumhauer, E.H.V., Ueber die Elementaranalyse organische Korper. Zeitschr. f. Analyt. Chem., Vol. V, p. 143, 1866.

[5] Mitscherlich, A., Neue Methoden zur Bestimmung der Zusammensetzung organischer Verbindungen, Zeitschr. f. Analyt. Chem., Vol. VI, p. 136, 1867.

combustion it is supplied by the mercury dioxide and its weight can be determined.

Maumené[1] has employed litharge and calcium phosphate and has calculated the oxygen supplied by the litharge for combustion of the organic material.

Determination of the Calorific Value

The calorific value of a coal is the heat developed by the combustion of a unit weight of the substance. It is usually expressed in terms of the *calorie* or the *British thermal unit* (B.t.u.). The calorie is the unit in the metric system and the standard calorie is the heat required to raise 1 gram of water 1° C. at the point of its greatest density (4° C.). It is, however, often stated more conveniently as the heat required to raise one gram of water from 15° to 16° C. The *large calorie* is the same except that a kilogram of water is used instead of a gram.

The standard British thermal unit (B.t.u.) which is generally employed by English-speaking engineers is the heat required to raise 1 pound of water from 39.1° F. to 40.1° F., this corresponding in the English system to the point of greatest density of the water. In recent years the unit is often described as the heat required to raise 1 pound of water from 60° to 61° F., or from 62° to 63° F., as this is a little more convenient and the latter figures are usually adopted in practice. The difference in all these cases is very small.

To express calories as British thermal units, multiply the number of calories by $\frac{9}{5}$ or 1.8.

The calorific value is sometimes expressed as the *real* calorific value and sometimes as the *industrial* calorific value. The real calorific value is the result obtained when complete combustion occurs in the laboratory in an apparatus such as the calorimeter and the industrial calorific value is the value obtained when the coal is burned under a boiler. The latter result approaches much more closely that which is obtained in industrial operations and it is always lower, owing to various losses, than the real value. It is measured as the heat necessary to vaporize large quantities of water and the weight of the coal used in some cases may be 1500 to 2000 kilograms.

[1] Maumené, J., Compt. Rend., Vol. 55, p. 432, 1862.

The Bomb Calorimeter

The calorimeter in some form has been in use at least since the time of Laplace and Lavoisier and it was practically perfected by Berthelot and Vielle, but it was not until Mahler took up the work for the Société d'Encouragement à l'Industrie Nationale in France that a satisfactory calorimeter for practical uses was designed. The early calorimeters contained a great deal of platinum and this made

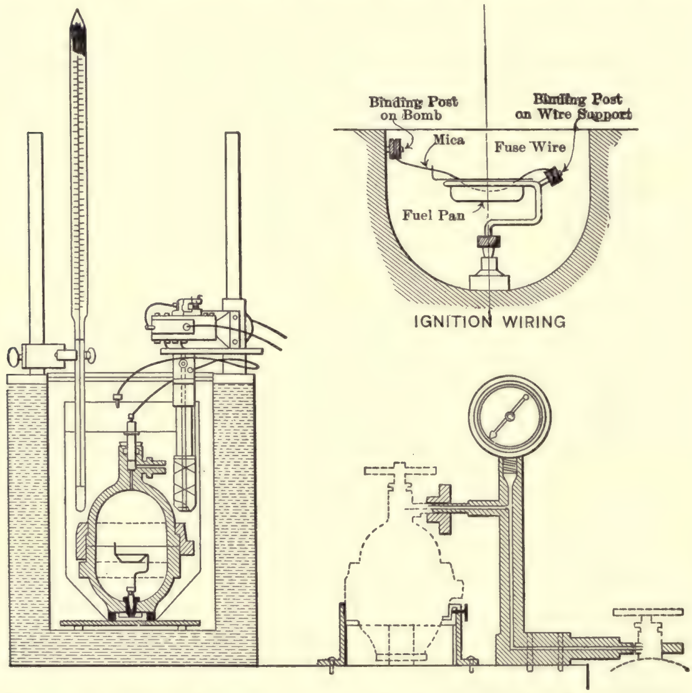


Fig. 12.—Emerson fuel calorimeter with diagram of bomb and pressure gauge and details of the ignition wiring.

them very expensive. The Mahler bomb calorimeter was so much cheaper and so efficient that this general type, now known under many modifications, is almost universally adopted. The calorimeters which may be used for standard determinations are the Emerson, Atwater, Davis, Peters, Parr, Mahler and Williams or similar types. One of the requirements is an inner surface of platinum, gold, porcelain, enamel or other material which is not attacked by products of combustion such as sulphuric and nitric acids.

Determination by calorimeter. — To determine the calorific value by means of one of these calorimeters of the Mahler type,[1] place 1 gram of 60-mesh coal on an asbestos mat in the platinum tray. The asbestos should be washed and ignited before using. The terminals of the firing circuit are connected by about 13 mg. of fine iron wire about 105 mm. long by 0.16 mm. in diameter. Platinum wire should be used if the bomb is platinum-lined and care must be taken to see that the terminals are clean. The wire is pressed down on the coal and the tray placed in the bomb. The lid is screwed down tightly on the lead gasket. Oxygen is forced into the bomb very slowly until the pressure within the bomb reaches 18 to 20 atmospheres with the needle-point valve closed just tight enough to avoid leakage.

The brass bucket is placed in the insulating jacket and the bomb, full of oxygen, is placed in the brass bucket which contains about 2000 to 2500 c.c. of distilled water. The quantity of water used varies with the type of calorimeter.

The stirring apparatus is adjusted so that it does not strike the bomb or bucket. The thermometer, which is graduated to 0.01° C. or, better, to 0.001° C., must not touch any metal parts and its bulb should be about 5 cm. from the bottom of the bucket. The terminals of the bomb are connected with wires leading to the switch. After the stirrer has been in motion until the water is thoroughly mixed the first reading of the thermometer is taken by means of a reading telescope attached to a cathetometer. The stirring is continued uniformly during the test and in a covered calorimeter the temperature should never be allowed to rise more than 1° C. above that of the water jacket.

Taking readings: The time required for the determination may be divided into the *preliminary* period, the *combustion* period and the *final* period. In the *preliminary* period five readings are usually taken one minute apart until the rate of change per minute is practically constant. After the fifth reading is taken a current of 75 volts is turned on for about one-half second thus starting the *combustion* period. The first two readings in this period are taken one-half minute apart because of the great change in ratio. The temperature rises to a maximum and then begins to fall. The readings

[1] Lord, N. W., and others. Analysis of coals. U. S. Bur. of Mines, Bull. 22, Part I, p. 17, 1913. Also Stanton and Fieldner, Op. cit., p. 26.

are made regularly every minute after the first minute and the first reading taken after the rate of fall becomes uniform is the last reading of the combustion period. The readings are continued every minute for five or six minutes composing the *final* period.

Calculation of the readings: The following plan shows the method of calculating the calorimeter readings (weight of sample 1.0000 grams).

	Time p. m.	Readings ° C.		
Preliminary Period	1.54	23.874	0.0058 rate of change per minute in preliminary period	
	.55	23.879		
	.56	23.885		
	.57	28.892		
				+ 0.0027[b]
	.58 (T)	23.897	+ 0.0058[a]	
Combustion Period	.585	24.160	+ 0.0049[a]	
				+ 0.0014[b]
	.59	25.430	+ 0.0008[a]	
				− 0.0006[b]
	.60	26.280	− 0.0020[a]	
				− 0.0023b
	2.01	26.439	− 0.0025[a]	
				− 0.0026[b]
	.02	26.463	− 0.0026[a]	
				− 0.0026[b]
	.03	26.466	− 0.0026[a]	
				− 0.0026[b]
	.04 (t)	26.463		− 0.0066 algebraic sum.
Final Period	.05	26.460		
	.06	26.458		
	.07	26.455	− 0.0026, rate of change in final period	
	.08	26.454		
	.09	26.450		

	26.463°
	23.897
Observed temperature change	2.566
Thermometer correction (Supplied with thermometer)	.002
	2.564
Heat loss	0.0066
	2.5706
Water equivalent	.3000
Total heat developed in calories	7,711.8
Correction	41.4
Heat developed by combustion of sample in calories	7,670.4

		Calories
Wire burned = 11.2 mg.	=	17.9
Titer (1 c.c. = 5 cal.) 2.5 c.c.	=	12.5
Sulphur (0.01 g. or 1 per cent = 13 cal.) 0.76 per cent	=	9.9
Room temperature = 24° C.		

a Computed rate per minute of temperature change at each reading: *b* Temperature correction for heat loss during each interval.

Let A equal the rate of change during the preliminary period and B equal the rate of change during the final period, then $A-B$ will equal the change in rate during the combustion period.

Let T equal the initial temperature of the combustion period and t the final temperature of the combustion period, then $T-t$ equals the apparent change in temperature during the combustion period. Then $\frac{A - B}{T - t}$ = the change in rate per degree of temperature change during the combustion period.

If the temperature readings during the combustion period be represented by t_1, t_2, t_3, etc., or in a general way by t_n, then the computed rate per minute of temperature change at each reading is found by the following formula:

$$A - (t_n - T)\frac{A - B}{T - t}.$$

To obtain the temperature correction for heat loss during each interval multiply the mean of the computed rate per minute of temperature change, for any two readings, by the interval in minutes. The algebraic sum of these corrections gives the total correction for heat loss (*e. g.* $-$ 0.0066° C.). This quantity is added to the observed temperature change, and this sum multiplied by the weight of the water plus the water equivalent of the apparatus gives the total heat developed.

Corrections for various factors: The observed temperature should be corrected for errors in the thermometer. The correction for the combustion of the iron wire is 1.6 calories per milligram. The correction for sulphur burned to sulphuric acid is 1.3 calories per milligram. The correction for nitrogen to aqueous nitric acid is made by titrating the bomb liquor with standard ammonia solution (0.00587 grams NH_3 per cubic centimeter). This solution is equivalent to 5 calories per cubic centimeter.

Analysis of the calorimeter washings: The calorimeter is thoroughly rinsed out after the combustion test is finished and the washings are titrated with standard ammonia solution (0.00587 gram per cubic centimeter) to make the acid correction. Methyl orange is used as an indicator. The nitric acid which is present is developed from the nitrogen in the coal and from the air imprisoned in the bomb. The solution also derives some acidity from the sulphur in

the coal. The sulphur is readily precipitated by barium chloride ($BaCl_2$) as in the Eschka method already described. Instead of the ammonia solution some analysts much prefer Stohman's solution, in which sodium carbonate (Na_2CO_3) is used, because of the greater regularity of the results obtained with it. One cubic centimeter of this solution contains 0.003706 gram sodium carbonate and it is equivalent to 0.004406 gram nitric acid. One calorie of heat is produced when this acid is formed. Methyl orange is used as indicator.

It is convenient to make the ammonia solution used of such strength that 1 c.c. is equivalent to 0.00483 gram of nitrogen because this weight of nitrogen burned to nitrogen pentoxide (N_2O_5), plus water generates 5 calories of heat.

When nitrogen burns to N_2O_5 + water 1035 calories of heat per gram are produced.

The ammonia solution is made up according to the following equation:

$$HNO_3 + NH_3 = NH_4NO_3.$$

Since $N = 14$ and $NH_3 = 17$,

$$14 : 17 = 0.00483 \text{ gram} : 00587 \text{ gram}.$$

Therefore 0.00587 gram NH_3 is equivalent to 0.00483 gram of nitrogen which when burned to nitric acid generates 5 calories of heat. The standard solution contains 5.87 grams of NH_3 per liter.

The ammonia used must also neutralize the sulphuric acid generated in the bomb from the sulphur and the strength of the ammonia solution in terms of the sulphur in the form of sulphuric acid is determined by the following equation:

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

$$2NH_3 : S = 34 : 32 = 0.00587 \text{ gram } NH_3 : 0.0055 \text{ gram S.}$$

The heat of combustion of the sulphur when converted into aqueous sulphuric acid is 4450 calories per gram of sulphur provided it is burned in oxygen at high pressure, as it is in the bomb. Since the heat of combustion of the sulphur burned under a boiler in industrial operations where it only changes to sulphur dioxide (SO_2), is reckoned as 2250 calories per gram of sulphur, a correction must be made, and the figure employed is 2200, or the difference between the above figures. Now, since 1 c.c. of the ammonia solution is equivalent to 0.0055 gram of sulphur, $0.0055 \times 2200 = 12.1$ calories. This is the

heat correction to be made on the basis that all the acidity in the washings from the bomb is due to the presence of sulphuric acid. A correction, however, must be made for the nitric acid as outlined above. The difference $12.1 - 5 = 7.1$ calories, and $7.1 \div 0.0055 = 1291$ calories per gram of sulphur, or practically 13 calories for each per cent of sulphur present.

Standardization of the calorimeter: A number of methods have been suggested for the determination of the water-equivalent of the calorimeter. One method makes use of the specific heats of the various portions of the apparatus. Another is the electric method, another the mixing of portions of water having different temperatures,[1] and still another the employment of different quantities of water while generating the same amount of heat in the bomb. None of these when considered from all points of view are as satisfactory for commercial operations as the method where substances of known calorific values are used. The calorific value of these substances is determined with elaborate electric apparatus by the Bureau of Standards and samples may readily be obtained. The substances mostly used are benzoic acid, naphthalene, and sucrose. A weighed portion of one of these substances is placed in the bomb and the experiment carried out just as for a sample of coal. The weight of the sample should be such that its calorific value will be as nearly as possible that of a gram of coal.

Method of calculating the relations between "air-dried," "as received," "moisture-free" and "ash-free" samples: The following system is adopted in calculating percentages in the "air-dried" sample to those in the "as received" sample:

[1] Bownocker, J. A., Lord, N. W., and Somermeier, E. E., Coals of Ohio. Ohio State Geol. Survey, Bull. 9, p. 331, 1908.

"Air-dried" condition	*"As received" condition*
Moisture at 105° C. multiplied by	$\frac{100 - \text{air-drying loss}}{100} +$ air-drying loss = moisture
Volatile matter " "	$\frac{100 - \text{air-drying loss}}{100}$ = volatile matter
Fixed carbon " "	$\frac{100 - \text{air-drying loss}}{100}$ = fixed carbon
Ash " "	$\frac{100 - \text{air-drying loss}}{100}$ = ash
Sulphur " "	$\frac{100 - \text{air-drying loss}}{100}$ = sulphur
Hydrogen " "	$\frac{100 - \text{air-drying loss}}{100} + \frac{\text{air-drying loss}}{9}$ = hydrogen
Carbon " "	$\frac{100 - \text{air-drying loss}}{100}$ = carbon
Nitrogen " "	$\frac{100 - \text{air-drying loss}}{100}$ = nitrogen
Oxygen " "	$\frac{100 - \text{air-drying loss}}{100} + \frac{8\ (\text{air-drying loss})}{9}$ = oxygen
Calorific value " "	$\frac{100 - \text{air-drying loss}}{100}$ = calorific value.

Calculating percentages in the "air-dried" sample to those in the "moisture-free" sample.

"Air-dried" condition	*"Moisture-free" condition*
Volatile matter multiplied by	$\frac{100}{100 - \text{moisture}}$ = volatile matter
Fixed carbon " "	$\frac{100}{100 - \text{moisture}}$ = fixed carbon
Ash " "	$\frac{100}{100 - \text{moisture}}$ = ash
Sulphur " "	$\frac{100}{100 - \text{moisture}}$ = sulphur
Hydrogen ($- \frac{1}{9}$ moisture) "	$\frac{100}{100 - \text{moisture}}$ = hydrogen
Carbon " "	$\frac{100}{100 - \text{moisture}}$ = carbon
Nitrogen " "	$\frac{100}{100 - \text{moisture}}$ = nitrogen
Oxygen ($- \frac{8}{9}$ moisture) "	$\frac{100}{100 - \text{moisture}}$ = oxygen
Calorific value " "	$\frac{100}{100 - \text{moisture}}$ = calorific value

(1 calorie = 1.8 B.t.u.)

To calculate the analyses to an "ash-free" and "moisture-free" basis use as denominator 100 − (moisture + ash) instead of "100 − moisture."

Calculation of the Calorific Value of Coal from the Analysis

The formula of Dulong is recognized as the most satisfactory formula so far devised for determining the calorific value from the analysis. It has, however, been modified in a number of ways. It is usually expressed as: Calorific value in calories per gram = 8080 C + 34,460 $\left(H - \frac{O}{8}\right)$ + S 2250, where C, H, O, and S, respectively, indicate the weights of the carbon, hydrogen, oxygen, and sulphur. This formula is not quite correct in view of the figures[1] lately obtained for the heating value of carbon, which should be approximately 8100 C instead of 8080 C, and 34,500 is a better figure to employ than 34,460.

To avoid the necessity of analyzing the coal for hydrogen Parr[2] uses the formula 8080 C + 34,500 "H" + 2250 S in which "H" represents the available hydrogen in the coal, or hydrogen not combined with oxygen to form water, and it is derived from a curve which is based on the principle that the hydrogen is united with some of the volatile carbon. He considers that the value for hydrogen so derived and used in Dulong's formula will produce results practically as satisfactory as those obtained from the original formula, and they are obtained much more readily.

The calorific value from the proximate analysis: If the calorific value could be calculated from the proximate analysis a great advance would be made over Dulong's formula. What appears to be a satisfactory method for computing the calorific value of certain coals from the proximate analysis, has been suggested by Goutal[3] as a result of experiments on over 600 specimens of various kinds of coal. He used the following formula:

$$P = 82\,C + a\,V \text{ in which}$$

P = the number of calories in a gram of fuel,

C = the percentage weight of fixed carbon, and

[1] Richards, Metallurgical calculations, Part I.

[2] Parr, S. W., Op. cit., p. 64.

[3] Goutal, M., Sur le pouvoir calorifique de la houille. Compt. Rend., Vol. 135, p. 477, 1902

V = the percentage weight of the volatile matter; while

a = a coefficient which varies with the percentage of volatile matter, V, in the pure coal.

a is found from a curve (Fig. 13). This curve is constructed by

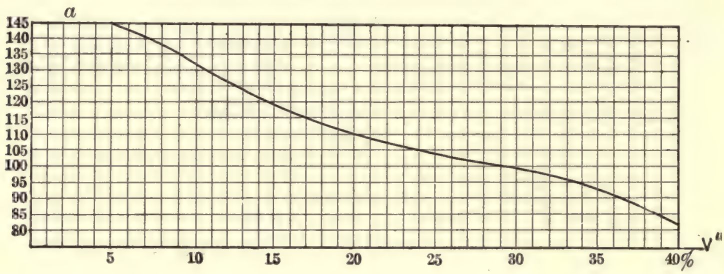


Fig. 13.—Goutal's curve for the determination of the calorific value of coal from the proximate analysis.

taking the values for V' as the abscissae and the values for a as the ordinates. V' is found from the formula

$$V' = \left(100 \frac{V}{C + V}\right)$$

and a was found as a result of a vast number of analyses which were made during this investigation. In the anthracites a = 100, a constant.

The values 5, 10, 15, 20, 25, 30, 35, 38, and 40 per cent for volatile matter in the pure fuel (V') give the corresponding figures for a as follows: 145, 130, 117, 109, 103, 98, 94, 85, and 80 per cent respectively.

For coals with a value for V between 5 and 35 per cent the variation between the results given by this method and those given by the calorimeter rarely vary more than 1 per cent. The value may reach 2 per cent in some anthracites and in weathered coals or lignites, and for these the calorimeter method is the only accurate means of determining their calorific value.

The following table from Carnot shows how closely the results obtained by Goutal's formula correspond to those obtained from Dulong's formula and the calorimeter. They are in every case closer to the calorimetric figures than are those from Dulong's formula.

	Fixed carbon	Volatile matter	Calorific Value by Various Means		
			Calorimeter	From Dulong's formula	From Goutal's formula
Anthracite of Pennsylvania	97.0	3.0	8256	8462	8380
Anthracite coal of Kéboa	94.8	5.2	8532	8528	8529
Anthracite coal of Creusot	89.6	10.4	8687	8704	8680
Semi-fat coal of Angers	85.9	14.1	8656	8750	8722
Fat coal of Porter	80.7	19.3	8667	8382	8740
Fat coal of Ronchamp	76.8	23.2	8797	8678	8702
Gas coal of Bethune	69.6	30.4	8668	8654	8671
Gas coal of Montrambert	65.7	34.3	8598	8407	8612

CHAPTER IV

VARIETIES AND RANKS OF COAL

Introduction

The various classifications of coal which have been suggested are discussed in another chapter. There are, however, certain varieties recognized almost universally in science and commerce which should be described in detail before a comprehensive description of the less familiar classifications can be given. These varieties are not sharply separated and they grade into one another, so that in describing them the proportions of their constituents must be stated as varying within wide limits. Two coals with a certain percentage of fixed carbon may have very different calorific properties owing to the fact that the moisture or the ash may vary considerably, and consequently if one constituent be chosen as a standard the others do not necessarily agree. An attempt has been made, therefore, to give the limits of variation as well as the average properties of these different varieties as they have been recognized by many writers from numerous countries. The ideal manner of presenting all the constituents other than moisture and ash, would be on a "moisture-free" and "ash-free" basis, but since the analyses selected have not been so recorded they have not been computed on this basis in the following figures unless it be so stated in the text.

Since it is so generally admitted that all coal has been derived from peat in some form and that it has arrived at its present state as the result of various geological processes, peat is briefly described with the varieties of coal. It is not regarded as a variety of coal, but rather as an incipient stage in the formation of that substance.

Peat (Fr. Tourbe, Ger. Torf). — Peat is an accumulation of vegetal matter which has suffered varying degrees of disintegration and decomposition, and it contains a high percentage of water and oxygen. It varies in physical character from a distinctly fibrous and woody, light-brown material to a dark-brown and black jelly-like substance. There are all gradations from peat to muck in which

mineral matter becomes so abundant as to prevent its free burning. Although it may be cut from the bog in blocks peat is seldom sufficiently compact to make a good fuel without compressing.

The composition of peat is illustrated by the following figures. Water in original samples from different parts of the bog is 62.98 to 90.12 per cent, usually 80 to 90 per cent. In a large number of analyses of dried specimens from various countries the following variations and averages in composition are shown:

	Variations	*Average*
Carbon	37.15–66.55 per cent	52.83 per cent
Hydrogen	4.08–10.39 "	5.97 "
Oxygen	18.59–42.63 "	33.12 "
Nitrogen	0.77– 3.10 "	1.34 "
Fixed carbon	10.39–33.91 "	23.59 "
Volatile matter	43.38–73.60 "	60.18 "
Ash	1.05–32.95 "	9.58 "

Sulphur is often as low as one-tenth of 1 per cent and it is usually below 1 per cent, but it may rise higher in pyritiferous types. The calorific value varies from 5500 to 10,000 B.t.u. in air-dried samples.

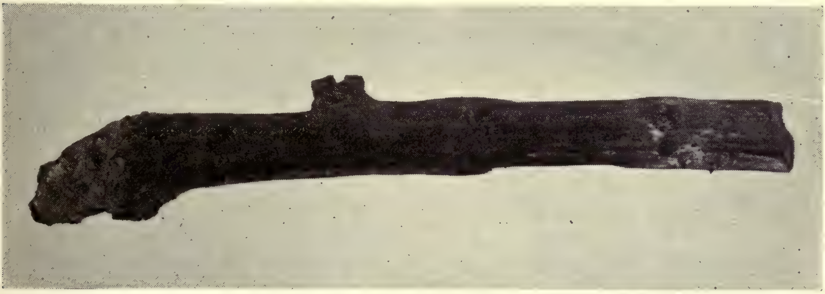


Fig. 14. — Branch of tree altered to lignite but preserving the original markings. From the coast of Alaska. (Collected by W. R. Crane.)

Dopplerite: This is a variety of peat, found chiefly in Styria but also occurring elsewhere in Europe, whose composition shows it to be highly acid. An analysis by Schrotter shows that it contains

Carbon	48.06 per cent
Hydrogen	4.98 "
Oxygen	40.07 "
Nitrogen	1.03 "
Ash	5.86 "

It is amorphous and in the fresh state is elastic like rubber. Its

luster is greasy and its specific gravity is 1.089. It burns with little or no flame and emits an odor like peat.

Lignite and brown coal (Fr. Lignite, Ger. Braunkohle). — There seems to be no definite record of the first use of the term lignite. It is a French word and may possibly have arisen from the term Lithanthrax ligneus which, according to Hausmann[1] was used by Wallerius[2] for the distinctly woody type of brown coal. It was used by Brongniart[3] as early as 1807 and it is generally found in all French works since that time. The German word, Braunkohle was used in different ways by Karst,[4] Neuss,[5] and Blumenbach[6] about the beginning of the nineteenth century.

In America the terms lignite and brown coal have come to be used interchangeably because both the amorphous and the xyloid, or woody types may be brown in color and may have similar chemical properties and uses. The two types grade into each other so that no sharp distinction can be made between them. In recent years, however, the United States Geological Survey has decided to adopt the term *subbituminous coal* for the compact, so-called "*black lignite*," and to restrict the term *lignite* to the lower grade brown coal which is usually, but not always more or less woody and on drying splits up into slabs.[7] (Plate III, Fig. 1.) The distinction is thus made on the basis of color. The composition of lignite or brown coal, as these terms are used in various countries, is indicated by the following figures compiled from numerous analyses of this coal from almost all parts of the world:

	Variation	*Average*
Moisture	0.75–43.00 per cent	14.42 per cent
Volatile matter	27.00–53.00 "	40.78 "
Fixed carbon	16.00–51.00 "	36.37 "
Ash	2.60–42.00 "	9.32 "
Sulphur	0.16– 9.00 "	1.14 "
Hydrogen		5.14 "
Carbon		58.14 "
Nitrogen		1.05 "
Oxygen		25.17 "

[1] Hausmann, J. F. Ludw., Handbuch der Mineralogie, Vol. 1, p. 79, 1813.

[2] Wallerius, J. G., Systema Mineralogicum, Vol. 2, p. 98, 1775.

[3] Brongniart, Alexandre, Traité élémentaire de Minéralogie, Tome 2, 1807.

[4] Karst, Mineralogische Tabellen 58, 1800.

[5] Neuss, Min. II, 3, 154.

[6] Blumenbach, Handbuch Der Naturgeschichte I, 660.

[7] Campbell, M. R., A practical classification of low-grade coals. Econ. Geology, Vol. 3, p. 134, 1908.

PLATE III.

Fig. 1.—North Dakota lignite showing characteristic fracture and xyloid texture.

Fig. 2.—Bituminous coal showing characteristic cubical fracture.

The calorific value of lignite, undried as received from the mine, is 5500–7000 B.t.u. — moisture-and-ash-free, 10,000–12,000 B.t.u. The specific gravity is 0.5 to 1.30. It colors brown a solution of potash. Some lignites in France are so high in pyrite that they can be used in the manufacture of iron sulphate and alum, and certain earthy varieties, known as *terre d'ombre* or *ombre de Cologne*,[1] are used for coloring matter.

Dysodile (Houille, or lignite papyracée): This is a laminated lignite high in siliceous ash. The color is a yellow to greenish-gray, the specific gravity 1.14 to 1.25. It burns readily with a bright flame and gives off an odor like asafetida. The ash has been found to contain abundant shells of diatoms. An analysis by Church[2] shows the following composition, ash free:

Sulphur	2.35	per cent
Hydrogen	10.04	"
Carbon	69.01	"
Nitrogen	1.70	"
Oxygen	16.90	"

It occurs in Tertiary formations, and is found in limestone in Sicily and in lignite in Germany and the Central Plateau of France.

Subbituminous coal. — This term has been officially adopted by the United States Geological Survey to include the glossy black coal which grades downward in properties from bituminous to lignite but which, as a rule, is of a considerably higher grade than the woody or ligneous type. It includes the *black lignite* and since it may be ligneous in texture it can in some cases be distinguished from brown coal in the field only by its black color, while it is separated from bituminous coal above by its mode of weathering. According to Campbell,[3] it parts along a surface nearly parallel to the bedding and thus breaks up into thin slabs, or it checks irregularly and does not disintegrate into cubes after the manner of bituminous coal. (Plate IV, Fig. 1.) The fracture is sometimes conchoidal. It often has a distinctly pitchy luster and is therefore sometimes called Pechkohle (pitch coal) by the Germans. Analyses of samples of this variety of coal as it is

[1] Moissan, Traité de chimie minérale, Vol. 2, p. 356, 1905.
[2] Church, A. H., Dysodile. Chem. News, Vol. 34, p. 155, 1876.
[3] Op. cit.

known in the United States show the following variations in percentage composition,[1]

Moisture	1.94–40.58	per cent
Volatile matter	7.50–70.86	"
Fixed carbon	18.00–83.00	"
Ash	2.06–55.40	"
Sulphur	0.15– 8.65	"
Hydrogen	1.76– 6.98	"
Carbon	30.68–86.85	"
Nitrogen	0.49– 2.13	"
Oxygen	2.80–52.18	"
Air-drying loss	0.80–28.00	"
Calorific value	6205–14,843	B.t.u.

Good grades of this coal have a calorific value of 8000 to 10,000 B.t.u.

Bituminous coal (Fr. Houille,[2] Ger. Schwarzkohle[3]). — The term bituminous has evidently been handed down from the earliest writers on mineralogy because they frequently spoke of the volatile materials given off this type of coal on distillation, as *bitumen*. Wallerius called this coal *Bitumen lapideum*. Among some modern writers there is a tendency to discard *bituminous* for the term *humic* since the coal lacks true bitumen in important amounts and contains a large percentage of humic acid.

Bituminous coal burns with a long yellowish flame and gives off a suffocating bituminous odor. It is more or less laminated as a rule, and the luster of the different layers varies greatly. It may be resinous, silky, pitchy, or dull and earthy. It soils the fingers when handled. The color varies from pitch-black to dark gray. The fracture may be irregular and somewhat splintery but it is almost always roughly cubical. (Plate III, Fig. 2.) It is, as a rule, conchoidal in cannel coal.

There are several types of bituminous coal. These include Caking and Non-caking coal — the latter including the Cherry and Splint coals of England, — Cannel coal and its related types, Torbanite and Boghead.

Caking or coking coal: This coal has the property of softening and running together into a pasty mass at the point of incipient decom-

[1] Lord, N. W., and others, Analyses of coals in the United States. U. S. Bur. Mines, Bull. 22, 1912.

[2] De Lisle, Vol. 2, p. 590, 1783. Hauy, Traité de minéralogie, Vol. 3, p. 316, 1801.

[3] Hausmann, Op. cit., p. 73.

position and then at higher temperatures giving off its volatile constituents as bubbles of gas. There remains a hard, gray, cellular mass called coke (Fr. Coke, Ger. Coaks). While there is no chemical or simple physical test which will distinguish coking coals in all cases, there are some tests which will usually indicate their coking properties. White[1] states that practically all coals with H : O ratios of 59 per cent or over seem to possess the quality of fusion and swelling necessary to good coking. Most with ratios down to 55 will make coke of some kind, while a few with ratios as low as 50 coke in the beehive oven, though very rarely producing a good article. Coals changing to anthracite, the weathered coals, and the coals of the boghead — cannel group show considerable variation from this rule. It has been shown, also, that the solubility of coal in aniline may be used as an indication of coking properites. Vignon[2] says that the coke given by the coal insoluble in aniline is powdery and that of the coal soluble in aniline is agglomerated and swollen.

A simple and, in many cases, a satisfactory test is that known as the agate mortar test. Coals which coke, when rubbed with a pestle in an agate mortar, cling to the sides of the mortar while the non-coking coals do not.[3]

Non-caking or non-coking coal: This coal may resemble the coking coal in all outward appearances but in composition it differs in the ratio of the hydrogen to the oxygen and it does not cling to the sides of an agate mortar when rubbed with the pestle. It burns freely without softening and it leaves a powdery mass instead of a strong cellular mass. The Cherry coal, so well known in England, is a variety of the non-coking coal. It received its name because of its fine luster. It is usually velvet-black in color, is brittle and crumbles rather readily. Splint coal or, as it is sometimes called, "Slate coal," is also an English name for a variety of non-coking coal. It is black and as a rule it has a resinous and glistening luster, but often it is dull and contrasts with the brilliant luster of the Cherry coal. It fractures in two directions, the longitudinal break being curved and slaty and the transverse uneven and splintery.

[1] White, David, The effect of oxygen in coal. U. S. Geol. Survey, Bull. 382, 1909.

[2] Vignon, Leo, Sur les dissolvants de la houille. Compt. Rend., Tome 158, pp. 1421–1424, 1914.

[3] Pishel, M. A., A practical test for coking coals. Econ. Geology, Vol. 3, pp. 265–275, 1908.

The composition of bituminous coal, as it has been recognized by different writers in various countries is as follows:

	Variation	*Average*
Moisture	0.04–34.33 per cent	2.50 per cent
Volatile matter	8.63–64.31 "	32.00 "
Fixed carbon	26.49–80.60 "	55.00 "
Ash	0.28–45.00 "	10.00 "
Sulphur	0.0012–10.5 "	0.80 "
Hydrogen	1.00– 8.80 "	4.80 "
Carbon	44.00–85.30 "	74.00 "
Nitrogen	1.00– 9.20 "	1.30 "
Oxygen	0.95–46.90 "	7.00 "
Calorific value	6840–15,169 B.t.u.	13,200 B.t.u.

The specific gravity varies from 1.15 to 1.5, with an average of 1.3. A good average for the percentage composition and calorific value of the bituminous coals collected in the United States between the years 1904 and 1910[1] is as follows:

Moisture	2.00–10.00 per cent
Volatile matter	25.00–40.00 "
Fixed carbon	45.00–65.00 "
Ash	5.00–12.00 "
Sulphur	0.50– 2.00 "
Hydrogen	4.50– 6.00 "
Carbon	60.00–80.00 "
Nitrogen	0.80– 2.00 "
Oxygen	7.00–20.00 "
Calorific value	12,000–14,500 B.t.u.

Cannel coal.[2] — This coal was originally known as *candle coal*, but the term cannel was employed by the earliest mineralogists. Kirwin[3] describes this coal, along with Kilkenny coal, as dull black in color and with conchoidal fracture when broken transversely. It burns with a bright lively flame and in some cases it may be kindled by the application of a match owing to the large percentage of highly volatile constituents which it contains. This property gave rise to the name *candle coal*. A variety of Scotch cannel which produces a marked crackling sound has been called *parrot coal* and Dana[4] mentions a variety from South Wales known as *horn coal* because, on burning, it emits an odor as of burning horn.

[1] U. S. Bur. of Mines, Bull. 22.

[2] Ashley, G. H., Cannel coal in the United States, U. S. Geol. Survey, Bull. 659, 1917.

[3] Kirwin, Richard, Elements of mineralogy. P. 215, 1784.

[4] Dana, E. S., A system of mineralogy. 6th ed., p. 1022, 1895.

Cannel coal is generally described as a non-coking bituminous type, but it is just within the boundary of a special group, the members of which are characterized by a higher percentage of volatile oils and gases than that found in ordinary bituminous coal. To this group Rogers applied the term *hydrogenous* or *gas* coals,[1] while Potonié[2] considers most of them as *sapropelic* types. Cannel undoubtedly consists chiefly of the spores of plants or *canneloid* and, as a result, differs markedly from ordinary coal in the character of the materials which compose it. (Fig. 15.) Beginning, therefore, with a different type of vegetal matter it is possible to have it pass through the stages corresponding to brown and to bituminous coal, still retaining its canneloid character. Its average composition is illustrated by the following analysis of Kentucky cannel:

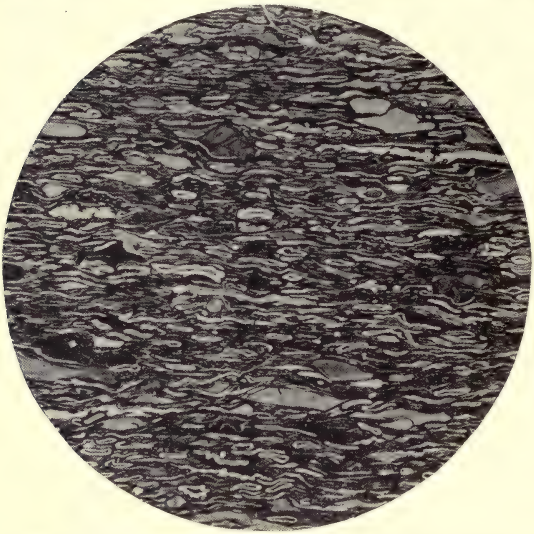


FIG. 15.—Photomicrograph of section of cannel coal consisting almost entirely of flattened spores. (Photo by E. C. Jeffrey.)

Moisture	2.36	per cent
Volatile matter	48.40	"
Fixed carbon	38.75	"
Ash	10.49	"
Sulphur	1.20	"
Hydrogen	6.47	"
Carbon	71.98	"
Nitrogen	1.16	"
Oxygen	8.70	"
Calorific value	13,770	B.t.u.

The specific gravity varies from 1.2 to 1.3.

[1] Rogers, H. D., Geology of Pennsylvania. Vol. 2, p. 990, 1883.

[2] Potonié, H., Die Enstehung der Steinkohle und der Kaustobiolith überhaupt, wie des Torfes, der Baunkohle, des Petroleums, u.s.w., 5th ed. 1910.

Torbanite: This is a variety of the boghead coals and it is named from Torbane Hill in Scotland where it has been mined for many years. It differs so much from ordinary coal that a prominent lawsuit was carried through the Scottish courts about the middle of the last century to determine whether the mining of the rock was governed by the laws controlling mineral or coal deposits. The trial was settled in favor of the latter. Like the other bogheads it is characterized by a very high percentage of volatile constituents including illuminating and lubricating oils, paraffin, and large quantities of illuminating gases, running from 14,000 to 18,000 cubic feet per ton. There is a difference of opinion concerning its origin, some regarding it as derived from spores, others from algae, and it is often described as a variety of cannel coal. The evidence is strongly in favor of the origin from spores rather than from algae. It is closely related to the kerosene shales and bituminous schists. Its color is dark brown, its surface dull and lusterless. The fracture is irregular to subconchoidal. According to Dana[1] the hardness is 2.25 and the specific gravity 1.17 to 1.2. Analyses quoted by the same authority show that the composition is approximately as follows, with ash excluded:

Hydrogen	11.48	per cent
Carbon	81.15	"
Nitrogen	1.37	"
Oxygen	6.00	"

The ash runs about 20 per cent. It is much higher in hydrogen than any ordinary type of coal.

Byerite: This is a term applied by Mallett[2] to a so-called mineral coal, somewhat resembling Torbanite but differing from it in not crackling in the fire, in being heavier — specific gravity 1.323 — and in melting and intumescing when heated. It gives a large amount of gas and tarry oils, about 30 per cent more than English cannel. An analysis gave the following results — moisture 6.02 per cent; volatile matter (gas and tarry oils) 39.95 per cent; fixed residue, consisting of coke and ash 54.03 per cent. The coke is a true coke but resembles the residue from the distillation of sugar and is too porous and crumbling to support a furnace burden. It is jet-black in color but gives a brown powder which does not color a potash solution brown. It is insoluble in carbon bisulphide, ether, or turpentine.

[1] Op. cit., p. 1022.

[2] Mallett, E. J., On Middle Park mineral coal. Am. Jour. of Sci., Vol. 9, p. 146, 1875.

Semibituminous coal. — H. D. Rogers[1] adopted this term for coal containing from 11 to 18 per cent volatile matter and to include what has been called *dry* bituminous coal, as opposed to the group of *fat* coals including caking coal, cherry coal, and splint coal. This type is, caking and, non-caking. In spite of the fact that on heating it softens and swells into a coke, this coke does not always agglutinate or cohere. Although the term is quite widely used in the United States, it seems a little unfortunate in view of the fact that the prefix *semi* conveys the idea that it should be a little below bituminous coal in the ascending scale from peat to anthracite, and it does not harmonize with the use of the term semianthracite. The term *superbituminous* might have been suggested as a more appropriate one. Rogers did not give any detailed description of this type of coal but various analyses from fields throughout the United States[2] show the varying proportions of the following constituents and their average in a good quality of this variety of coal:

	Variation	*Average*
Moisture	0.78– 8.99 per cent	2.00– 4.00 per cent
Volatile matter	7.40–23.84 "	14.00–18.00 "
Fixed carbon	57.11–80.89 "	70.00–80.00 "
Ash	1.80–34.15 "	4.00– 8.00 "
Sulphur	0.44– 6.47 "	0.50– 1.20 "
Hydrogen	3.34– 5.17 "	4.00– 5.00 "
Carbon	51.23–85.54 "	76.00–82.00 "
Nitrogen	0.81– 1.82 "	1.00– 1.50 "
Oxygen	3.38–13.70 "	4.50– 6.50 "
Calorific value	8386–14,814 B.t.u.	14,000–15,000 B.t.u.

Semianthracite. — This name was adopted by Rogers[3] at the same time as the term semibituminous, to cover the coal between semibituminous and anthracite. He describes it as possessing to a lesser degree the properties characteristic of anthracite. The conchoidal fracture is not so well developed as in anthracite, and the cleats are more numerous. It crumbles more readily in the fire and owing to a greater percentage of volatile matter it kindles more readily than anthracite and emits a small amount of yellow flame when ignited. Owing to more rapid consumption its efficiency is greater than that of anthracite for certain purposes. The volatile

[1] Rogers, H. D., Geology of Pennsylvania, pp. 988–990, 1858.
[2] Analyses of coals in the United States. Bur. of Mines, Bull. 22, 1912.
[3] Op. cit.

PLATE IV.

FIG. 1.—Subbituminous coal showing irregular fracture.

FIG. 2.—Pennsylvania anthracite showing typical conchoidal fracture.

matter varies from 6 to 11 per cent and averages from 7 to 8 per cent. The specific gravity is about 1.4. Analyses of this type of coal from the United States[1] indicate the following range in composition:

Moisture	1.96– 7.94	per cent
Volatile matter	6.81–32.46	"
Fixed carbon	58.24–82.00	"
Ash	4.33–14.50	"
Sulphur	0.57– 4.05	"
Hydrogen	3.69– 4.81	"
Carbon	72.43–80.00	"
Nitrogen	0.51– 1.45	"
Oxygen	5.46–10.02	"
Calorific value	12,460–14,184	B.t.u.

A proximate analysis of a good grade of this coal is represented by the following:

Moisture	1.94	per cent
Volatile matter	9.95	"
Fixed carbon	79.00	"
Ash	8.80	"
Sulphur	0.29	"

Anthracite (Fr. Anthracite, Ger. Glanzkohle). — The first use of this term among mineralogists is ascribed to Hauy,[2] although *Anthrazit* may have been employed by Karst[3] ten years earlier. In America this coal is frequently known as *hard coal*, and in Wales as *culm* or *stone coal.* It is characterized by an iron-black color, and dull to brilliant, and even submetallic luster. It does not soil the fingers as bituminous coal does. It burns with a short, pale blue flame, emits little odor, and does not coke. It commonly breaks with conchoidal fracture and thus differs from bituminous coal which usually breaks into roughly rectangular fragments (Plate IV, Fig. 2). When very small fractures are numerous, the freshly broken surface shows small rounded or oval, eyelike forms and it has then been called "Bird's-eye" coal.

The calorific value of anthracite is not as great as that of semi-bituminous or high grade bituminous coal because it does not develop a high temperature so rapidly. This is owing to the small amount of readily combustible material compared with the fixed carbon. It is

[1] Analyses of coals in the United States. Bur. of Mines, Bull. 22, 1912.

[2] Traité de minéralogie, Tome III, p. 307, 1807.

[3] Op. cit.

much sought after for domestic use on account of its lack of soot and dust and because of the fact that it burns so much longer than other types of coal.

Anthracite reaches the maximum hardness in coal. It varies from 2 to 2.5 in Moh's scale. Certain varieties of this coal are capable of being cut and polished for ornamental purposes and some of that from the Hazleton and Summit Hill districts of Pennsylvania is used for this purpose.

Like that of all other coals, the composition of anthracite as it has been mined in different regions varies greatly. The following figures show the variation in the analyses from various sources.

Moisture	0.42– 5.61	per cent
Volatile matter	1.72–10.75	"
Fixed carbon	73.71–90.90	"
Ash	3.20–30.09	"
Sulphur	0.17– 2.60	"
Hydrogen	1.89– 5.61	"
Carbon	78.41–83.89	"
Nitrogen	0.63– 1.57	"
Oxygen	3.80–11.54	"
Calorific value	9230–13,298	B.t.u.

The specific gravity varies from 1.27 to 1.7.

The anthracite from Rhode Island is not included in the above list. There the coal is in places graphitic, the moisture in the mine sample runs as high as 23 per cent and the fixed carbon as low as 49 per cent because of very high ash, although the volatile matter is as low as 2.5 per cent. The ash may be over 30 per cent and the oxygen is high except in the dried samples. The nitrogen is usually below 0.5 per cent. The pecific gravity of the Rhode Island anthracite varies from 1.43 to 2.2[1]

The following averages represent the percentage composition of good anthracite calculated on a *moisture-free* and *ash-free* basis:

Volatile matter	1.50– 6.50	per cent
Fixed carbon	93.00–98.00	"
Sulphur	0.50– 1.50	"
Hydrogen	1.75– 4.00	"
Carbon	90.00–94.00	"
Nitrogen	0.60– 1.25	"
Oxygen	1.25– 2.75	"
Calorific value	14,500–15,000	B.t.u.

[1] Ashley, G. H., Rhode Island coal. U. S. Geol. Survey, Bull. 615, 1915

The moisture will run from 2.5 to 4 per cent and the ash from 1.5 to 10 per cent.

The specific gravity of Pennsylvania anthracite varies from 1.42 to 1.65,[1] and of the Welsh anthracite from 1.29 to 1.45, averaging about 1.33.

COMPARATIVE COMPOSITION OF WOOD, PEAT, AND COALS

Table showing the relative percentage composition of wood, peat, and coals.

Kind of Fuel	Proximate analyses				Ultimate analyses						Calorific value	
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Air-drying loss	Calories	B. t. u.
Wood	....	....	....	....	....	6.25	49.50	1.10	43.15	....	....	5,800
Peat *a*	56.70	26.14	11.17	5.99	0.64	8.33	21.03	1.10	62.91	53.40	1,992	3,586
Do *c*	....	60.37	25.80	13.83	1.48	4.69	48.57	2.54	28.89	....	4,600	8,280
Lignite *a*	34.55	35.34	22.91	7 20	1.10	6.60	42.40	0.57	42.13	15.50	3,939	7,090
Do *b*	....	60.67	39.33	....	1.89	4.74	72.79	0.98	19.60	....	6,762	12,172
Subbituminous *a*	24.28	27.63	44.84	3.25	0.36	6.14	55.28	1.07	33.90	16.20	5,209	9,376
Do *b*	....	38.12	61.88	....	0.50	4.74	76.28	1.47	17.01	....	7,188	12,938
Bituminous *a*	3.24	27.13	62.52	7.11	0.95	5.24	78.00	1.23	7.47	1.80	7,733	13,919
Do *b*	....	30.26	69.74	....	1.06	5.39	87.00	1.37	5.18	....	8,626	15,527
Cannel *a*	1.70	50.76	38.23	9.31	1.02	6.83	73.25	1.31	8.28	0.40	7,917	14,251
Do *b*	....	57.04	42.96	....	1.15	7.46	82.31	1.47	7.61	....	8,896	16,013
Semibituminous *a*	2.03	14.47	75.31	8.19	2.26	4.14	79.97	1.26	4.18	1.40	7,823	14,081
Do *b*	....	16.12	83.88	....	2.52	4.37	89.07	1.40	2.64	....	8,713	15,683
Semianthracite *a*	3.38	8.47	76.65	11.50	0.63	3.58	78.43	1.00	4.86	2.60	7,309	13,156
Do *b*	....	9.95	90.05	....	0.74	3.76	92.15	1.18	2.17	....	8,587	15,457
Anthracite *a*	2.80	1.16	88.21	7.83	0.89	1.89	84.36	0.63	4.40	1.50	7,388	13,298
Do *b*	....	1.29	98.71	....	1.00	1.77	94.39	0.71	2.13	....	8,268	14,882

(*a*) Sample as received.

(*b*) Same sample calculated to an ash- and moisture-free basis.

(*c*) Sample calculated to a moisture-free basis.

Peacock coal. — Peacock coal is not a distinct variety of coal but rather a condition in which either anthracite or bituminous coal may be found. It is of considerable interest in some localities because of its beauty and abundance. It has received its name from its iridescent colors which resemble those o the peacock in their changing lights. This play of colors is similar to that produced by a film of oil or of iron oxide on water and is due to the same cause, viz., refraction and interference of the rays of light in passing through the film. This coal is found only in the upper levels of the mine, par-

[1] Stoek, 22d Ann. Rept., U. S. Geol. Survey, p. 74, 1900–1901.

ticularly where the seam and roof slate are much fractured, thus permitting surface waters to percolate through the fissures in the coal and to deposit thin films of iron oxide along the cracks. The film may in a few cases be due to traces of crude oil or to sulphur dioxide but the main cause is the iron oxide produced by the oxidation of iron pyrite near the surface where the oxygen of the air can attack the iron sulphide. That it might be due in some rare cases to sulphur dioxide gas, which may be set free in the weathering of iron sulphide, is suggested by the fact that a burning sulphur match brought close to a fragment of coal will often produce a similar iridescent film on the surface of the coal.

Other Combustible Substances Entering Into the Composition of Some Coal Seams

Jet (Fr. Jayet, Ger. Gagath, Greek, Gagates). — This is a black, rather fibrous to compact substance capable of taking a good polish and used in Europe for the manufacture of ornaments, especially for those worn in mourning. Formerly an industry on a small scale was carried on in France at Sainte-Colombe sur l'Hero, Département de l'Aude. In Yorkshire, England, a few tons of this material have been produced and it is said to have been worth about a shilling a pound. The composition of jet is as follows:[1]

Volatile matter	37.90	per cent
Ash	1.70	"
Carbon	61.40	"

Its specific gravity varies from 1.26 to 1.3.

Jet is generally described as a variety of lignite but Prestwich[2] speaks of it as a wood converted into a sort of cannel coal. While jet may resemble cannel a little in physical character, from our present knowledge of cannel it is evident that it cannot resemble it in origin since all writers agree that jet is altered wood while cannel is made up almost entirely of plant spores. The jet found in the Jurassic rocks on the Yorkshire coast of England is believed from structure detected in thin sections to have been formed mainly from coniferous wood which was allied to the Araucarian pines. It is also considered that the trees drifted to their present position since the jet is now

[1] Descloizeaux, A., Manuel de minéralogie, Tome 2, p. 332, 1893.
[2] Prestwich, J., Chemical, physical, stratigraphic geology, p. 142.

found associated with Ammonites and other marine fossils. It occurs in Asia Minor, Spain and Bohemia as well as in England and France.

Natural coke or carbonite. — In certain cases where igneous rocks have intruded bituminous coal seams the coal has been transformed into natural coke more or less resembling artificial coke but usually differing from the latter chiefly in the percentage of the volatile constituents which it contains and in its more compact character. Taff[1] has suggested that the greater percentage of volatile constituents in the natural coke may be due to the lack of opportunity for the escape of these gases and to the possible accession of gases to the coke from the adjacent coal seam after it has cooled. The coke shows a typical columnar structure varying in degree of perfection of the columns (Fig. 16), and with the columns normal to the surface of contact between the igneous rock and the coal which has been coked. The extent to which the coal is coked varies greatly. Other things being equal, there will be a fairly close relation between the thickness of the coked zone and that of the igneous rock, the former varying directly as the latter, but no definite rule can be established because cases have been noted where almost no observable coking has occurred, while in other cases the coal is coked out of all proportion to the size of the intruding rock. This condition is well understood when one considers that

FIG. 16. — Natural coke, or carbonite from Hesse (specimen in collection of Muséum Nationale d'Histoire Naturelle, Paris).

[1] Taff, J. A., Natural coke in the Wasatch Plateau. Science, N. S., Vol. 23, p. 696, 1906.

igneous masses entering the coal seams at various times or in different places may vary greatly in temperature and in the amount of the hot vapors and gases which they carry. In some cases the latter may escape along the bedding planes in the coal deposits and conduct the heat some distance from the igneous rock. The basic igneous rocks, being more fluid than the acid are often capable of intruding themselves into narrow fissures in ways in which the more viscous acid rocks cannot.

In the United States natural coke is common in Colorado, Utah, and New Mexico, and it is also abundant in Mexico[1] and Alaska where the coals have been extensively intruded by igneous rocks.

This coke has a regular fracture, is dark gray to iron-black in color, and its texture varies from distinctly porous to compact. The luster is graphitic to submetallic. It often grades into anthracite which in turn passes into the bituminous coal of the seam. In most places it makes excellent fuel. The following analyses indicate the percentage composition of the coke, the adjacent coal, and a sample of artificial coke.

	I	II	III	IV	V	VI	VII	VIII*	IX*	X*
Moisture	8.10	0.32	0.57	3.86	13.42	3.28	0.184			
Volatile matter	40.20	20.38	0.39	35.34	5.83	1.64	0.552	20.30	12.20	4.70
Fixed carbon	45.91	65.90	78.24	53.28	61.50	89.14	88.726	79.70	87.80	95.30
Ash	5.76	13.10	20.80	7.52	19.25	9.22	9.993	8.29	9.73	45.96
Sulphur			0.54	0.64	0.48	0.83	0.533	2.07	1.11	0.15
Hydrogen				5.48	3.39					
Carbon				72.66	61.55					
Nitrogen				1.17	0.81					
Oxygen				12.53	14.52					
Air-drying loss				2.60	11.60					
B.t.u.				13,068	9895					

I. Analysis quoted by Taff of coal in seam in Wasatch Plateau.

II. Natural coke from same seam.

III. Natural coke from Cokedale Mine, Colorado. U. S. Bur. of Mines, Bull. 22, pt. 1, p. 69.

IV. Coal taken 1 foot from natural coke and 2½ feet from a dike. Walsen Mine, Colorado. Op. cit. under III, p. 65.

V. Same locality as IV but close to small dike and coke.

VI. Artificial coke.

VII. Artificial coke from the coal of the Connelsville basin, Pa. U. S. Geol. Survey.

VIII. Coal in the seam removed from the influence of the eruptive.

IX. Coal 0.3 metres from the igneous rock.

X. Coal in contact with the eruptive.

* Analyses by G. von Rath. Contactverhältnisse Zwischen Kohle und einem basischen Eruptivgestein bei Fünfkirchen: Neues Jahrbuch, I, pp. 274–277, 1880.

[1] Dumble, E. T., Natural coke of the Santa Clara Coal-Field, Sonora, Mexico. Trans. Am. Inst. Min. Eng., Vol. 29, pp. 546–549, 1899.

The greater percentage of ash shown in the analyses of the coke than in the analyses of the coal from the same seam is often only relative, but in some cases it is probable that silica and possibly other mineral constituents have been added to the seam by the igneous rock in its immediate vicinity.

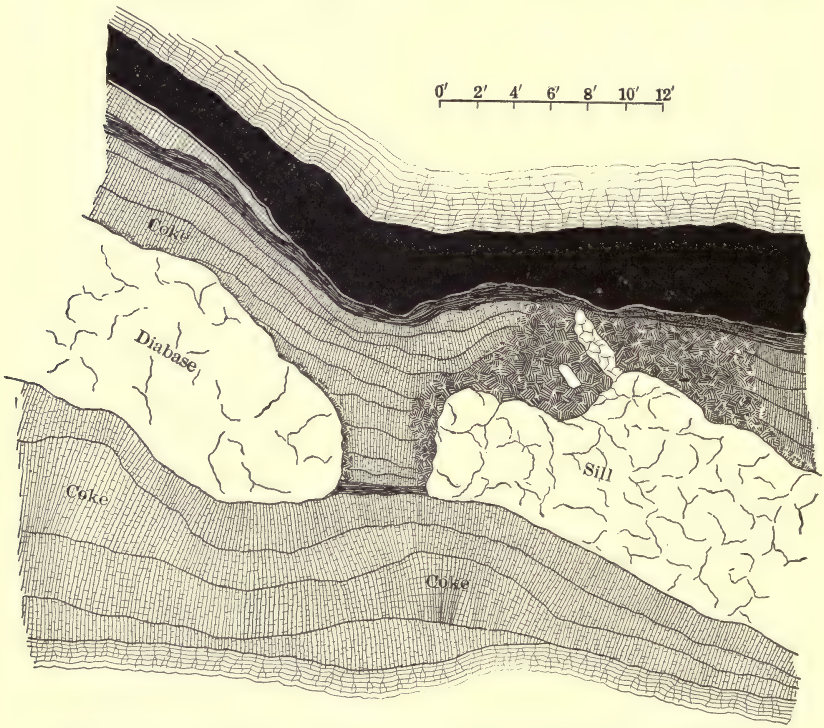


FIG. 17.—Intrusion of diabase into a coal seam in Alaska, producing natural coke. (From a sketch by W. R. Crane.)

Mineral charcoal or "mother of coal" (Fr. Fusain). — In the different varieties of coal from lignite to anthracite there are dull laminae, lenses, and irregular bands of a black to dark-grey material which, on account of its resemblance to charcoal is known as "mineral charcoal" or among many of the miners as "mother of coal." It may take the form of an iron-gray, almost powdery material or it may show the outline of blackened fragments still retaining some of the original woody structure and fibers. In some cases even the most delicate structures of the leaf are preserved. When cut with a knife it shows much the same consistency

as wood charcoal but is more sooty and crumbling. It soils the fingers. Various explanations have been offered for its origin. Daubrée[1] in 1844 ascribed it to forest fires started by lightning, burning in the swamps where the coal vegetation was laid down. As early as 1858 Rogers[2] recognized that it was due to some alteration which the vegetation suffered before being buried and this explanation is supported by White,[3] who considers that the association of the various woody materials, the preservation of the rods, and the delicate fern-leaf fragments make the forest fire hypothesis untenable. He believes that the charcoal has originated as a result of the greater amount of decomposition which the vegetation suffered before being buried in the bog. On the other hand, Jeffrey[4] still clings to the theory that the forest fire was the agent which produced the charcoal.

A consideration of the actions of forest fires in our modern swamps and peat-bogs in the northern portions of the continent, in addition to the arguments put forth by White, oppose the forest fire hypothesis. It is seldom that the fire leaves the charred materials in such quantities in proportion to the ash and in such associations in relation to the coarse and fine fragments as that in which they must generally have been left to produce the deposits now found in coal. It is possible that an occasional mass of charcoal resulted from fire but improbable that the greater part of the mineral charcoal was produced in that way. The best explanation is found in the greater alteration of the vegetal matter in parts of the swamp exposed to dry rot where the water was low.

It is evident that carbonite and mineral charcoal have at times been confused by some writers.[5]

Analyses show that mineral charcoal usually differs considerably in chemical composition from the other portions of the coal seam in which it occurs. The following analyses were made from a seam in which the charcoal occurs irregularly throughout the mine and is there known as "mother of coal." It is not found over 9 inches from the bottom of the seam and it always pinches out gradually. The

[1] Daubrée, A., Compt. Rend., Vol. 19, p. 126, 1844.

[2] Rogers, H. D., Geology of Pennsylvania, Vol. 2, p. 993, 1858.

[3] White and Thiessen, The origin of coal. U. S. Bur. of Mines, Bull. 38, p. 33, 1913.

[4] Jeffrey, E. C., Jour. of Geology, Vol. 23, p. 218, 1915.

[5] Heinrich, O. J., The Mesozoic formation in Virginia. Trans. Am. Inst. of Min. Eng., Vol. 6, pp. 243–244, 1877–78.

thickness of the charcoal varies from zero to 3 inches. There are usually very small bright streaks running through the dark gray, which always has a dull luster. The writer is indebted to Mr. H. B. Northrup for these analyses.

	I	II
Moisture	0.62 per cent	0.23 per cent
Volatile matter	23.05 "	7.11 "
Fixed carbon	68.86 "	90.99 "
Ash	7.47 "	1.67 "
Sulphur	1.19 "	0.23 "

I. The coal from a seam in the Glenview Mine, Decatur Twp., Clearfield Co., Pa.
II. Mineral charcoal from the same seam.

Resinous substances. — In addition to the substances described there are often found in coals, particularly in the younger and less altered coals such as the lignites, large and small masses of amber-like substances which represent the resins from various trees growing in the coal swamps.[1] To these the name *Retinite* is often applied in a general way. In the Tertiary lignites near Gore, New Zealand, masses of this retinite as large as a man's head may be seen and in some of the lignite of the western United States resins are found in considerable quantities. The following are examples of these resins from coal seams in various localities.[2]

Ambrite ($C_{40}H_{66}O_5$ approx.): A yellowish-gray, subtransparent, amorphous resin which breaks with a conchoidal fracture. The hardness is 2 and the specific gravity 1.034. The luster is greasy. It becomes strongly electrified when subjected to friction. An analysis by Maly shows:

Ash	0.19 per cent
Hydrogen	10.58 "
Carbon	76.53 "
Oxygen	12.70 "

It burns with a yellow smoky flame. It is insoluble in ether, oil of turpentine, benzine, chloroform, and dilute acid.

This resin is described by Hochstetter as occurring in large masses in several of the coal fields of New Zealand. It is so much like the Kauri gum of the North Island that it is sometimes exported with it.

[1] White, David, Resins in Paleozoic plants and in coals of high rank. U. S. Geol. Survey, Prof. Paper 85 E, 1914.

[2] For full description of these and related substances see Dana's System of mineralogy, pp. 1002–1014, 1892. Also, Descloizeaux, Manuel de minéralogie, Tome 2, p. 34, 1893.

Bathvillite: This substance forms dull brown lumps in the Torbanite in Scotland and since it usually occurs as a cavity filling it is not known whether it is a resin or a secretion from the Torbanite which it resembles in composition although containing less oxygen.

Duxite: A dark brown, opaque resin from the lignite at Dux, Bohemia. Its specific gravity is given as 1.13 and its chemical composition according to Fischer is as follows:

Moisture	2.72	per cent
Ash	1.94	"
Sulphur	0.42	"
Hydrogen	8.14	"
Carbon	78.25	"
Oxygen	13.19	"

This is in general similar to Muckite and Walchowite except that they are lighter colored. Neudorfite from the coal beds at Neudorf, Moravia is very similar in composition.

Middletonite: This substance, which was named by Johnston[1] from the Middleton Collieries near Leeds, England, occurs about the middle of the main coal in little round masses. These masses are seldom larger than a pea and are generally in thin layers less than $\frac{1}{16}$ inch in thickness between the layers of coal. It is hard and brittle, and its specific gravity is about 1.6. In color it is reddish-brown in reflected light and deep red in transmitted light. The luster is resinous. It blackens on exposure to the air and then cannot readily be distinguished from the coal except by its luster. It is unaffected by heat at 400° F. and it burns like resin. It is soluble in cold sulphuric acid but it is very slightly soluble in alcohol, ether and oil of turpentine. An analysis shows the following composition:

Hydrogen	8.007	per cent
Carbon	86.437	"
Oxygen	5.563	"

The formula suggested is ($C_{20}H_{10} + H_2O$) which resembles that for the hydrate of the oil of turpentine.

Succinite: This substance is commonly known as amber. It is found in considerable quantities on the coast of the Baltic. It occurs as irregular masses which have a conchoidal fracture. The hardness is about the same as that of anthracite coal, 2–2.5, and the specific gravity is 1.05 to 1.09. The color is yellow or reddish-brown and the luster resinous. It is negatively electrified by friction and it softens

[1] Johnston, F. W., The Phil. Mag., Vol. 12, p. 261, 1838.

at 150° C. Its composition is represented by the following analysis by Schrotter:

Hydrogen	10.22	per cent
Carbon	78.82	"
Oxygen	10.94	"

There is usually a little sulphur present in the form of an organic compound. Succinite occurs in the bituminous coals of the southern part of France and in lignite in various localities.

Wheelerite: In the Cretaceous lignite beds of New Mexico Loew[1] found a yellowish resin filling fissures and interstratified with the coal. This was named Wheelerite after Lt. G. M. Wheeler. The composition is as follows:

Hydrogen	7.31	per cent
Carbon	73.11	"
Oxygen	19.58	"

It is almost entirely dissolved in alcohol or ether and is partially soluble in carbon bisulphide. It is soluble also in sulphuric acid, producing a brown solution, and with nitric acid it evolves nitrous fumes. It melts at 154° C.

There are numerous other resins similar in many respects to those described above. Among these might be mentioned Ionite from the lignite of Ione Valley, California; Köflach from the Tertiary brown coals of Styria; Rosthornite, the brown to garnet-red material which forms lenticular masses in the coal of Carusthia; Schleretinite from the Coal Measures of Wigan, England; Tasmanite from the bituminous shales of Tasmania; Trinkerite which forms large amorphous masses of a hyacinth-red to chestnut-brown color in the brown coal near Albona, Istria. Pyroretinite which resembles the resin of Pinus abies is said to occur in masses from the size of a nut to that of a man's head in the brown coal near Ausseg, Bohemia. Its specific gravity runs from 1.05 to 1.18 and its hardness about 2.5. Rochlederite occurs in large reddish-brown resin-like masses in the brown coal of Zweifelsruth in Eger, Bohemia.

[1] Loew, O., On wheelerite, a new fossil resin. Am. Jour. Sci. 3d Series, Vol. 7, p. 571, 1874.

CHAPTER V

THE CLASSIFICATION OF COALS

Introduction

There have been in use since the earliest days of the coal trade certain names which distinguish different varieties of coal, such as anthracite, bituminous, and lignite. These names, or their equivalents, are in general use almost throughout the world. As the importance of the coal trade increased, however, it was realized that some more definite means of classifying coals according to their composition and heating value was desired because the lines of distinction between the varieties used in the past were not sufficiently definite for practical purposes.

Frazer's Classification

One of the first in this country to attempt a definite classification of coals on the basis of their composition and heating value was Persifor Frazer, Jr.[1] He based his classification on the ratio of the fixed carbon to the volatile combustible matter (C : V.Hc). He states that as early as 1844 W. R. Johnson had used the same principle and had recognized the ratio of the volatile to fixed combustible matter as a logical basis for the classification of coals. After various attempts to make the fuel ratio of the different coals fit the descriptions of the varieties suggested by H. D. Rogers in 1858, Frazer concluded that it is only possible to classify the coals according to their fuel ratio within wide limits, and suggests the following divisions:

	$\frac{C}{V.Hc}$
Hard-dry anthracite	100–12
Semianthracite	12–8
Semibituminous	8–5
Bituminous	5–0

The table is deficient for modern use because it does not distinguish

[1] Frazer, Persifor, Jr., Classification of coals. Second Geol. Survey of Pennsylvania, Rept. M. M., pp. 128–144, 1879. Also Trans. Am. Inst. Min. Eng., Vol. 6, pp. 430–451, 1877, and Vol. 36, p. 825, 1906

subbituminous coal and lignite from bituminous coal and as stated by Frazer the ratio limits had to be arbitrarily chosen. The table represents, however, a considerable advance over any previous work and it sets forth a principle which has become deeply established in the coal trade.

In discussing Frazer's classification, A. S. McCreeth[1] calls attention to the fact that the sulphur content of the coal should be taken into consideration since it is partly volatilized in coking, and he suggests that the portion volatilized should be subtracted from the volatile hydrocarbon percentage and added to that of the fixed carbon.

Classification on basis of Moisture Content

In 1903 Collier[2] suggested that all coals with a moisture content of 10 per cent or more should be classed as lignite, and those with less than 10 per cent as bituminous, but his classification has proved entirely unsatisfactory.

Campbell's Classification

After extensive studies of coal for the purpose of obtaining a satisfactory classification Campbell[3] came to the following conclusions: (1) For the higher grades of coal the fuel ratio may be used as a satisfactory means of separation but it does not properly separate the lignites and bituminous coals. (2) The percentage of fixed carbon cannot be used as a satisfactory basis. (3) The calorific value cannot be used since many of the bituminous coals are of higher calorific value than the best grades of anthracite. It is, however, fairly satisfactory for the lignites and bituminous coals. (4) The percentage of hydrogen present is valueless as a basis of classification. (5) A classification according to the carbon content is satisfactory in a general way as there is a fairly regular decrease in the carbon content from that of anthracite to that of lignite. The separation between anthracite and semibituminous is not marked and there are many exceptions to the rule. (6) The carbon-hydrogen ratio is regarded as the most satisfactory basis for classification.

[1] McCreeth, A. S., Second Geol. Survey of Pennsylvania, Rept. M. M., p. 157, 1879.

[2] Collier, A. J., Coal resources of the Yukon, Alaska; U. S. Geol. Survey, Bull. 218, 1903.

[3] Campbell, M. R., The classification of coals. Am. Inst. of Min. Eng., Vol. 36, p. 324, 1906. Also, Report on the operation of the coal testing plant. U. S. Geol. Survey, Prof. Paper 48, pt. 1, 1906.

He then groups the coals as follows in a tentative classification, the ratios of the higher coals being rather indefinite owing to lack of ultimate anlyses.

		Carbon-Hydrogen Ratio.
Group A	(Graphite)	∞–(?)
Group B	(Anthracite)	(?)–30(?)
Group C		30(?)–26(?)
Group D	(Semianthracite)	26(?)–23(?)
Group E	(Semibituminous)	23(?)–20
Group F	(Bituminous)	20–17
Group G		17–14.4
Group H		14.4–12.5
Group I		12.5–11.2
Group J	(Lignite)	11.2– 9.3
Group K	(Peat)	9.3– (?)
Group L	(Wood, Cellulose)	7.2

Seyler's Carbon-Hydrogen Classification

Seyler[1] had previously published the following classification. It is based on the hydrogen and carbon in the pure coal. The genera, which are arranged vertically, are distinguished by their hydrogen content while the species are arranged horizontally and separated according to their percentage of carbon. This table is taken from Pollard.[2]

[1] Seyler, C. A., Chemical classification of coal. Proc. S. Wales Inst. Eng., Vol. 21, p. 483 and Vol. 22, p. 112. Also, Colliery Guardian LXXX pp. 17–19, 80–82 and 134–136.

[2] Strahan, A., and Pollard, W., The coals of S. Wales. Mem. Geol. Survey of England and Wales, 2d ed., pp. 58–59, 1915.

Carbon	Anthracitic	Carbonaceous	Bituminous			Lignitious	
			Meta.	Ortho.	Para.	Meta.	Ortho.
	Carbon over 93.3	93.3–91.2	91.2–89.0	89.0–87.0	87.0–84.0	84–80	80–75
Perbituminous genus Hydrogen over 5.8 per cent			Perbituminous (Per-metabituminous)	Perbituminous (Per-orthobituminous)	Perbituminous (Per-parabituminous)	Perlignitious	
Bituminous genus Hydrogen 5.0–5.8 per cent		Pseudobituminous species	Metabituminous	Orthobituminous	Parabituminous	Lignitious (Meta)	(Ortho)
Semibituminous genus Hydrogen 4.5–5.0 per cent		Semibituminous species (Orthosemibituminous)	Subbituminous (Sub-metabituminous)	Subbituminous (Sub-orthobituminous)	Subbituminous (Sub-parabituminous)	Sublignitious (Meta)	(Ortho)
Carbonaceous genus Hydrogen 4.0–4.5 per cent	Semianthracitic species	Carbonaceous species (Orthocarbonaceous)	Pseudocarbonaceous (Sub-metabituminous)	Pseudocarbonaceous (Sub-orthobituminous)	Pseudocarbonaceous (Sub-parabituminous)		
Anthracitic genus Hydrogen under 4 per cent	Orthoanthracitic	Pseudoanthracite Subcarbonaceous	Pseudoanthracite Sub-metabituminous	Pseudoanthracite Sub-orthobituminous	Pseudoanthracite Sub-parabituminous		

Pollard shows that in the coals analysed from the Welsh field the hydrogen-carbon ratio falls fairly satisfactorily into Seyler's classification. The carbon-hydrogen ratios given by the U. S. Geological Survey do not fit the Welsh anthracites very well as many of them have a ratio below 26.

Grout's Classification based on Carbon Content

In an article published the year after Campbell's classification appeared, Grout[1] criticizes the use of the carbon-hydrogen ratio as not being reliable and states that if total carbon in ash- and moisture-free coal had been considered the separation between lignite and bituminous coal would have been very satisfactory. The chief objection made to the carbon-hydrogen ratio is the fact that although the hydrogen content of lignite and bituminous coal is not so very different, the variation may amount to one-third of the total and thus give a large difference in ratio in coals which are not markedly different in other respects; on the other hand, it may throw two coals together which are unlike in many important respects. The difficulty in sampling the low grade coals so that all collectors may be able to get the same amount of moisture and therefore the same amount of hydrogen in the coal from the same seam is a further objection to Campbell's carbon-hydrogen ratio since it is based on too variable a factor.

The following is Grout's classification based on fixed carbon for those coals above bituminous, and on fixed carbon and total carbon for bituminous coals and those of lower grade.

Graphite	Fixed carbon over 99	per cent
Anthracite	Fixed carbon over 93	"
Semianthracite	Fixed carbon 83–93	"
Semibituminous	Fixed carbon 73–83	"
Bituminous:		
High grade	Fixed carbon 48–73	"
	Total carbon 82–88	"
Low grade	Fixed carbon 48–73	"
	Total carbon 76.2–82	"
Cannel	Fixed carbon 35–48	"
	Total carbon 76.2–88	"
Black lignite	Fixed carbon 35–60	"
	Total carbon 73.6–76.2	"
Brown lignite	Fixed carbon 30–55	"
	Total carbon 65–73.6	"
Peat and turf	Fixed carbon below 55	"
	Total carbon below 65	"
Wood		

Parr's Classification

Parr,[2] in his classification, considers that the term *volatile combustible* as it has generally been used is incorrect since it includes some

[1] Grout, F. F., The composition of coals. Econ. Geology, Vol. 2, pp. 225–241, 1907.

[2] Parr, S. W., Illinois Geol. Survey, Bull. 3, 1906. Also, The classification of coals. Jour. Am. Chem. Soc., Vol. 28, p. 1425, 1906.

hydrogen, oxygen, and nitrogen, which are non-combustible. The hydrogen present as hydrocarbons is combustible but that combined with oxygen in water is not. For example, in a Pocahontas coal with 18.7 per cent volatile matter 14.5 per cent is combustible hydrocarbons and 4.2 per cent is non-combustible hydrogen, oxygen and nitrogen. This inert matter should be taken into consideration since it is not an asset to the fuel.

In this classification total carbon (C) and fixed carbon (fc) are determined from analysis. The volatile carbon (vc) unassociated with hydrogen is obtained by subtracting the percentage of fixed carbon from that of total carbon (C − fc = vc). The *inert volatile matter* is obtained by subtracting from 100 per cent the sum of total carbon + sulphur + ash + water + hydrogen, which is not united with oxygen in water and is, therefore, free to burn and produce heat. To reduce this remainder to a pure fuel basis it is divided by 100 less the sum of ash and water. The derived formula on which the following table is based is $vc\,\frac{100}{C}$. This ratio serves to differentiate the coals above bituminous. In the bituminous and lower grades of coal the inert volatile matter, which is so much more abundant in these coals, is taken into consideration. The classification is as follows:

			$vc\,\frac{100}{C}$	Inert volatile
Anthracitic	Anthracites proper		Below 4	
	Semianthracites		4–8	
	Semibituminous		10–15	
Bituminous	Bituminous proper	A	20–32	5–10
		B	20–27	10–15
		C	32–44	5–10
		D	27–44	10–15
	Black lignite		27 up	16–20
	Brown lignite		27 up	20–30

In taking examples of the various analyses of coals tested by the U. S. Geological Survey at the St. Louis plant, Parr[1] shows that they readily follow this classification.

[1] U. S. Geol. Survey, Prof. Paper 48, 1906.

A further formula is suggested for the purpose of determining what Parr chooses to call the "gross coal index," or the amount of any coal necessary to give 100 pounds of pure fuel. It is found by adding together the carbon, sulphur ,and combustible hydrogen, (these three constituents being regarded as the only true heat-producing factors in the coal) dividing the sum by 100, and 100 by the quotient. Thus a Dakota lignite contains: *C* 52.66 per cent; *H* 1.83 per cent; and *S* 2.02 per cent = 56.51. The "gross coal index" for this coal would be $\frac{100}{.5651} = 177$, or it would require 177 pounds of it to make 100 pounds of pure fuel.

Grout's classification resembles this one of Parr's in providing two factors for fixing the position of the coal and it has the advantage of being simpler in its application.

White's Classification based on Carbon − Oxygen + Ash Content

Another method of classifying coals has been suggested by White[1] in making determinations of the anti-calorific influence of oxygen. As a result of an investigation of all available ultimate analyses it was found that ash and oxygen possess almost equal anti-calorific values, the former having slightly more than the latter. This was found to be true also for moisture-free coal. If two coals alternate in the percentages of ash and oxygen while the other constituents remain constant the calorific value changes very little. Since carbon is the principal calorific element in the fuel it seems appropriate that it should be taken as one factor and (oxygen + ash) as the other in determining the calorific value. It is found, therefore, that the ratio C : (O + ash) gives a quotient which corresponds very closely to the determined calorific value of the coal, not varying more than 1 per cent, as a rule, from an efficiency curve. The sulphur, available hydrogen $\left(H - \frac{O}{8}\right)$ and nitrogen seem to play a small part in controlling the calorific value of the fuel compared with that of the carbon, oxygen, and ash. The hydrogen is the most potent element of the three and its influence is shown in the special types of coal such as those of the boghead-cannel group.

[1] White, David, The effect of oxygen in coal. U. S. Geol. Survey, Bull. 382, 1909.

It was found, further, that the relation of the ratio C : (O + ash) to the calorific value becomes much less distinct in coals undergoing anthracitization and having over 79 per cent fixed carbon in the pure fuel, or in those which have been weathered.

This classification is of great scientific interest in its bearing on the calorific value of coals but it has little application in classifying coals according to the terms which are familiar in the coal trade.

There is one strong objection, from a practical standpoint, to all the preceding classifications except that of Frazer in the fact that they require ultimate anlyses. If possible, the making of ultimate analyses for classification purposes should be avoided since they are always costly. Parr has met this objection to a considerable degree by devising an apparatus by means of which the total carbon may be readily determined and he has also prepared a curve from which the available hydrogen may be obtained. This curve is constructed on the principle that the available hydrogen is combined with volatile carbon in the form of hydrocarbons and that the percentage of available hydrogen, therefore, bears a fairly definite relation to the percentage of volatile carbon. Since the latter is easily obtained by subtracting the fixed carbon from the total carbon it is not difficult to obtain the available hydrogen from the curve.

Dowling's Split Volatile Ratio Classification

In order to avoid the necessity of making an ultimate analysis Dowling[1] has suggested a classification based on what he calls the "*split volatile ratio.*" This system is adopted in order to take into account the volatile matter, which is available for the production of heat and that portion which is inert and therefore should be placed with the moisture as anti-calorific material. The formula used is,— $\frac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile combustible}}{\text{Moisture} + \frac{1}{2}\text{ volatile combustible}}$. When the quotients resulting from this ratio are compared with those obtained from the carbon-hydrogen ratio they are found to be almost equally satisfactory. The various coals may be grouped according to this classification in the following order:

[1] Dowling, D. B., Classification of coals by the split volatile ratio. Can. Min. Jour. pp. 143–146, April 15, 1908. Also, Can. Geol. Survey, Rept., No. 1035, p. 43.

Anthracite	15 up
Semianthracite	13–15
Anthracite coal	10–13
High carbon bituminous	6–10
Bituminous	3.5–6
Low carbon bituminous	3–3.5
Lignitic coal	2.5–3
Lignite	1.2–3.5

This split volatile ratio was adopted in part of the following classification of the coals of the world by the Twelfth International Geological Congress[1] and also in a later work by Dowling on the coal resources of Canada.[2]

Classification Adopted by the International Geological Congress

CLASS A

(1) Burns with short, blue flame; gives off 3 to 5 per cent of volatile combustible matter.

Fuel ratio: $\frac{\text{Fixed carbon}}{\text{Volatile matter}} = 12$ and over.

Calorific value, 8000 to 8330 calories, or, 14,500 to 15,000 B.t.u.

Mean composition,

Carbon	93 to 95	per cent
Hydrogen	2 to 4	"
Oxygen and nitrogen	3 to 5	"

(2) Burns with slightly luminous, short flame and little smoke; does not coke, and yields from 7 to 12 per cent of volatile matter.

Fuel ratio, 7 to 12.

Calorific value generally 8300 to 8600 calories, or 15,000 to 15,500 B.t.u.

Mean composition,

Carbon	90 to 93	per cent
Hydrogen	4 to 4.5	"
Oxygen and nitrogen	3 to 5.5	"

CLASS B

(1) Burns with short, luminous flame and yields 12 to 15 per cent volatile matter; does not readily coke.

Fuel ratio, 4 to 7.

[1] Coal resources of the world. Vol. 1, Toronto, Canada, 1913.

[2] Coal fields and coal resources of Canada. Can. Geol. Survey, Mem. 59, 1915.

Calorific value generally 8400 to 8900 calories, or 15,200 to 16,000 B.t.u.

Mean composition,

Carbon	80 to 90 per cent
Hydrogen	4.5 to 5 "
Oxygen and nitrogen	5.5 to 12 "

(2) Burns with luminous flame and yields from 12 to 26 per cent volatile matter; generally cokes.

Fuel ratio, 1.2 to 7.

Calorific value 7700 to 8800 calories, or 14,000 to 16,000 B.t.u.

Mean composition,

Carbon	75 to 90 per cent
Hydrogen	4.5 to 5.5 "
Oxygen and nitrogen	6 to 15 "

(3) Burns freely with long flame; withstands weathering but fractures readily and occasionally has moisture content up to 6 per cent; volatile matter up to 35 per cent; makes porous, tender coke.

$$\frac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile}}{\text{Hygroscopic moisture} + \frac{1}{2}\text{ volatile}} = 2.5 \text{ to } 3.3$$

Calorific value 6600 to 7800 calories, or 12,000 to 14,000 B.t.u.

Mean composition,

Carbon	70 to 80 per cent
Hydrogen	4.5 to 6 "
Oxygen and nitrogen	18 to 20 "

Class C

Burns with long, smoky flame; yields from 30 to 40 per cent volatile matter on distillation, leaving very porous coke. Fracture generally resinous.

Calorific value 6600 to 8800 calories, or 12,000 to 16,000 B.t.u.

Class D

Contains generally over 6 per cent of moisture; disintegrates on drying; streak brown or yellow; cleavage indistinct.

(1) Moisture in fresh-mined, commercial output, up to 20 per cent. Fracture generally conchoidal.

Drying-cracks irregular, curved lines.

Color generally lustrous black, occasionally brown.

$$\frac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile}}{\text{Hygroscopic moisture} + \frac{1}{2}\text{ volatile}} = 1.8 \text{ to } 2.5$$

Calorific value 5500 to 7200 calories, or 10,000 to 13,000 B.t.u.

Average composition,

Carbon	60 to 75 per cent
Hydrogen	6 to 6.5 "
Oxygen and nitrogen	20 to 30 "

(2) Moisture in commercial output over 20 per cent. Fracture generally earthy and dull.

Drying-cracks generally separate along bedding planes and often show fibrous (woody) structure.

Color generally brown, sometimes black.

Calorific value 4000 to 6000 calories, or 7000 to 11,000 B.t.u.

Average composition,

Carbon	45 to 65 per cent
Hydrogen	6 to 6.8 "
Oxygen and nitrogen	30 to 45 "

In the above classification, letters are substituted for names. In a general way the classification conforms to the nomenclature used in America, as follows:

A_1 = Anthracite coal.

A_2 = Semianthracite coal.

B_1 = Anthracitic coal and high carbon bituminous coal.

B_2 = Bituminous coal.

B_3 = Low carbon bituminous coal.

C = Cannel coal.

D_1 = Lignitic or subbituminous coal.

D_2 = Lignite.

Gruner's Classification

In his classification of French coals Gruner[1] takes into consideration the fixed carbon and volatile matter as well as the constituents of the ultimate analysis. He also makes use of the ratio of hydrogen to (oxygen + nitrogen). No provision is made for lignite, subbituminous coal, or cannel. The following table is a slightly abbreviated compilation of Gruner's tables. As previously mentioned the term "houille" in French corresponds to bituminous coal in America, and "charbon" is the general term used for coal.

[1] Gruner, E., and Bousquet, G., Atlas général des houillères. Deuxième partie, Texte p. 16, 1911.

Class or type of coal and commercial name in France	Proportion of coke in 100 parts of pure coal	Proportion of volatile matter in 100 parts of pure coal	Nature and appearance of coke	Real calorific power	Industrial calorific power. Water at 0° vaporised at 112° by 1 kgm. of pure coal burned
	Per cent	Per cent		Calories	Kgms. of water
1. Houilles sèches (dry) à longue flamme. Houilles flambantes.	55–60	45–40	Powdery or slightly fused.	8000–8500	6.70–7.50
2. Houilles grasses (fat) à longue flamme. Charbons à gaz.	60-68	42–32	Completely agglomerated and very often fused.	8500–8800	7.60–8.30
3. Houilles grasses (fat) proprement dites. Charbons de forge et Houilles maréchales (smiths).	68–74	32–26	Fused and more or less swollen.	8800–9300	8.40–9.20
4. Houilles grasses (fat) à courte flamme. Charbons à coke.	74–82	26–18	Fused, compact.	9300–9600	9.20–10.00
5. Houilles maigres (lean) ou anthraciteuses charbons demi-gras. Charbons quart-gras.	82–90	18–10	Slightly fused, very often powdery.	9200–9500	9.00–9.50
6. Anthracites. Charbon maigre (lean) anthracite.	90–92	10–8	Powdery, often decrepitated.	9000–9200	9.00

Carbon	Hydrogen	Oxygen and Nitrogen	Ratio $\frac{O+N}{H}$	Designation in Germany (Ruhr Basin)	Designation in Belgium	Designation in England
Per cent	Per cent	Per cent				
1. 70–80	5.5–4.5	19.5–15.5	Between 4 and 3	Flamm-Kohle	Flénus secs	Splint coal
2. 80–85	5.8–5.0	14.2–10.0	Between 3 and 2	Gas-Kohle	Flénus gras ou Mons	Gas coal
3. 84–89	5.0–5.5	11.0–5.5	Between 2 and 1	Fett-Kohle		Caking coal
4. 88–91	5.5–4.5	6.5–4.5	Nearly 1	Fett-Kohle	Charbons durs ou Charleroi	Steam coal
5. 90–93	4.5–4.0	5.5–3.0	Less than 1	Mager-Kohle		
6. 93–95	4.0–2.0	3.0	1–0.5	Anthrazit	Anthracite	Anthracite

A number of experiments have shown that the lean (maigre) coals are almost insoluble in the ordinary solvents such as aniline while there is an increasing proportion of the fuel soluble, in passing from the lean to the fat (gras) coals.

Ashley's Use Classification

A classification has recently been suggested by Ashley[1] which is intended primarily for the use of the person engaged in the coal business and which he designates as a "Use Classification." The main factors on which this classification are based are two ratios, the first being the ratio of the *fixed carbon* to *volatile matter* and *moisture* combined $\frac{\text{F.c.}}{\text{V.m.} + H_2O}$ and the second the fuel ratio and the *fixed-carbon-moisture* ratio (F.c.m. ratio). A double ratio is thus made use of as in some of the previous classifications described. The higher-rank coals are distinguished by their *fuel ratio* and the lower ranks by the ratio of the moisture "as received" to fixed carbon. These ratios are chosen because in the higher ranks of coal the moisture changes little and the volatile matter much in relation to the fixed carbon when one rank of coal is changed to another higher in the scale by geological processes, while in the lower ranks there is a larger proportional change in the moisture than in the volatile matter with respect to the fixed carbon. The physical properties are also taken into consideration since they depend largely upon the genesis of the coal and must therefore be closely related to the chemical properties. For example cannel coal differs greatly from ordinary bituminous coal because of its different origin. The woody character of low-grade coals is also considered.

A new departure in this classification is the adoption of locality names for certain ranks and grades of coal. The coal of a distinctive grade from a well-known mining locality takes the name of the locality with the name changed so as to end in *ite*. As examples, Pocahontas coal would be known on the market as Pocahontite and Hocking Valley coal as Hockingite. In addition to the use of these terms for coal from those fields the names might be applied to the same grade of coal from other localities, thus adopting the use of locality names as they are used in mineralogy.

[1] Ashley, G. H., A use classification of Coal. Trans. Amer. Inst. Min. Met. Eng. LXIII, p. 782, 1920.

The following tables show examples of the application of these ratios to the analyses of various typical coals throughout the country. The first table shows the ratio of fixed carbon to volatile matter and moisture combined, and the second the fuel ratio and fixed-carbon-moisture ratio.

RATIO OF FIXED CARBON TO VOLATILE MATTER AND MOISTURE COMBINED $\left(\frac{\text{F.c.}}{\text{V.m.} + H_2O}\right)$

Coal	Ratio	Coal	Ratio
Anthracite	10.7+	Saint Clair Co., Ill. coal	0 96
Bernice coal	6.8	Sangamon Co., Ill. coal	0.84
Brushy Mountain, Va. coal	4.8	Grundy Co., Ill. coal	0.78
Pocahontas coal	3.7	Sheridan, Wyo. coal	0.68
Sewell, New River, coal	2.8	Carney, Wyo. coal	0.62
Connellsville coal	2.0	Gillette, Wyo. coal	0.56
Pittsburgh coal	1.6	Wood Co., Tex. lignite	0.50
Beaver River, Pa. coal	1.2	Houston Co., Tex. lignite	0.43
Gallatin Co., Ill. coal	1.09	Williston, N. Dak. lignite	0.37

FUEL RATIO AND FIXED-CARBON-MOISTURE RATIO
(F.c.m. ratio.)

Coal	Fuel ratio	Carbon moisture	Coal	Fuel ratio	Carbon moisture
Anthracite	10+	10+(30±)	Saint Clair Co., Ill.	1.4–	4.0–6.0
Bernice	7–10	10+(27±)	Sangamon Co., Ill.	1.4–	2.5–4.0
Brushy Mountain, Va.	5–7	10+(26+)	Grundy Co., Ill.	1.4–	2.0–2.5
Pocahontas	3.5–5	10+(24.5)	Sheridan, Wyo.	1.4–	1.7–2.0
Sewell	2.5–3.5	10+(23)	Carney, Wyo.	1.4–	1.4–1.7
Connellsville	1.85–2.5	10+(21.5)	Gillette, Wyo.	1.4–	1.0 –1.4
Pittsburgh	1.4–1.85	10+(19.5)	Wood Co., Tex.	1.4–	0.85–1.00
Beaver River, Pa.	1.4–	10+(17)	Houston Co., Tex.	1.4–	0.65–0.85
Gallatin Co., Ill.	1.4–	6.0–10.0	Williston, N. Dak.	1.4–	0.5 –0.65

From these tables it is seen that the lignites fall between 0.5 and 1 in the fixed-carbon-moisture ratio, most of the subbituminous coals between 1 and 2 and the bituminous coals between 2 and 10+. Above this point the fuel ratio is used as a basis of separation.

From a physical standpoint all coals are first divided into those of compact texture and those of woody, fibrous, or earthy texture. Those of compact texture are next divided into an *anthracite* class and a *bitumite* class. The anthracite class has a fuel ratio of 7+ and

a non-luminous flame, and the bitumite class a fuel ratio of less than 7 and a luminous flame. The latter class includes the bituminous and subbituminous coals.

The anthracites are further divided into true, hard anthracites with conchoidal fracture, high specific gravity and submetallic luster and the soft anthracites with semi-cubic fracture and low specific gravity — such as the so-called anthracite at Bernice, Sullivan Co., Pa. The dividing line between these two groups is a fuel ratio of 10.

The bitumites are divided first into those with a B.t.u. value of over 14,300 and those with a value less than that when calculated on a coal free of moisture, ash and sulphur. The calculation is made from the following formula:

$$\text{B.t.u. (ash-, moisture-, sulphur-free)} = \frac{\text{B.t.u. (coal as received)} - 40\ \text{S.}}{100 - (\text{moisture} + \text{ash} + \text{sulphur})}$$

The higher rank bitumites are divided into the Virginites, or so-called smokeless coals, having a fuel ratio between 2.5 and 7, and those with a fuel ratio below 2.5. The former have a short to medium flame and the latter a long flame.

The Virginites are divided into three types having fuel ratios respectively between 5 and 7; between 3.5 and 5; and between 2.5 and 3.5. The first type is a non-caking coal while the other two are caking coals. The Pocahontas type has a fuel ratio of 3.5–5 and the Sewell type a ratio of 2.5–3.5. The other group of the high grade bitumites is divided into the caking or steam coals and the non-caking or household coals. The caking, long-flamed coals are again divided into two groups based on a fuel ratio of 1.4. Those above this figure are called the Pennsites from their abundance in Pennsylvania. The Pennsites are again divided into Connellsite with a fuel ratio of 1.85 or more and Pittsite with a fuel ratio between 1.4 and 1.85. These names are taken from the Connellsville and Pittsburgh districts.

Those coals with a fuel ratio below 1.4 and a fixed-carbon-moisture ratio of more than 6 are called Ohioites and those with a similar fuel ratio but with the other ratio less than 6, but still in the bitumite class, are called Illinoites. The Ohioites are again divided into the Belmontites with a fixed-carbon-moisture ratio of more than 10 and Hockingites with a ratio between 6 and 10. The Illinoites which are high-moisture coals are also subdivided.

The non-caking or household coals are divided into two groups, the splintites and the cannellites, wh ch are separated on a physical basis as their structure and fracture are quite different. The lower-rank bituminous coals with a fuel value of less than 14,300 B.t.u. on the ash-, moisture- and sulphur-free basis are divided into two groups according to their weather resisting properties.

For the convenience of those persons who purchase coal by wire Ashley has suggested letters to designate the various ranks of coal and the grades in those ranks. The table of letter abbreviations for the grades is as follows:

	Ash per cent	Sulphur per cent	Fusibility of ash, degrees F.
Vl = very low	0– 4	0.00–0.75	Less than 2200
l = low	4– 8	0.75–1.5	2200–2400
m = medium	8–12	1.5 –2.5	2400–2600
h = high	12–20	2.5 –4	2600–2800
Vh = very high	20+	4 +	2800+

The letters *a*, *s*, and *f* also stand for ash, sulphur and fusibility respectively. The fusibility of the ash is an important factor in the heating quality of the coal because of the effect it may have in clogging the grates, and it should be given serious consideration.

This classification may appear complicated to the average man dealing in coal; there will be many exceptions to the classes made and people long accustomed to such terms as Pocahontas coal may at first object to the use of Pocahontite for coal from another region; yet there are a number of features in this classification wh ch commend it. One important one is the fact that a proximate analysis furnishes the necessary data for making the computations

After a review of all available classifications of coal it must be concluded that no one classification so far suggested meets with general approval. Some of the classifications are very satisfactory in combining the physical and chemical properties of certain of the coals so that they coincide with the names familiar to the public, and firmly established in the coal trade. Others are applicable to certain other coals and it seems probable that when the number of analyses has been greatly increased and our knowledge of the controlling chemical factors in coals has become somewhat more advanced it will be possible to formulate a classification which will be workable under most con-

ditions at least. Some of the classifications may now be applied to certain regions with satisfactory results, but it is improbable that any one will ever be applicable to all kinds of coals from all districts, owing to the great diversity of physical and chemical characters resulting from the variations in the vegetal matter from which coals have been derived and in the variable geological conditions under which they have been developed. The classifications, therefore, which require more than two factors as a basis for determination of a type come nearer satisfying the fundamental requirements than those which are based on a ratio between only two constituents, and from a practical standpoint the making of ultimate analyses by the present chemical methods is to be avoided when possible.

CHAPTER VI

THE ORIGIN OF COAL

Introduction

In the earlier days of geological science a few theorists, searching for some abstruse explanation for the origin of coal seams suggested that they were intruded into the enclosing strata as bituminous deposits of igneous origin in the same manner that sills of igneous rock are injected between beds of sediments. Patrin regarded the seams as extrusions of bituminous matter on the sea bottom. So definite is the evidence, however, that all coal has resulted from the alteration of vegetal matter in some form, that a theory of origin based on any other premise may be dismissed without consideration. Any one questioning this conclusion has but to observe the transition from peat to lignite and from lignite to bituminous coal, with a gradual decrease in the distinctness of the plant remains in passing from the lower to the higher grades of coal, to be convinced regarding this matter. Many of even the hard coal seams contain remnants of trees completely changed to coal but retaining the markings of the bark and other woody structures. The modern application of the microscope to the study of those coals which show to the naked eye no evidence of plant remains reveals the spores, the fragments of resin and the modified woody tissue of the vegetation which formed the coal.

Although it is almost universally agreed that all the varieties of coal originated from vegetal matter there is much difference of opinion regarding its mode of accumulation into such great bodies as those which gave rise to the coal seams. There is also a great divergence of opinion among geologists and paleobotanists regarding the processes by means of which the vegetation has been brought into the form of brown coal, bituminous coal, or anthracite, in which it is now found.

Theories for the Accumulation of the Vegetal Matter[1]

There are two main theories for the accumulation of the vegetal matter giving rise to coal seams, and there are two schools of geologists supporting these theories. One school contends that the plant remains accumulated *in situ*, that is, where the vegetation grew and fell, and the deposit is said to be *autochthonous* in origin. The other considers that the deposit is *allochthonous*, that it has accumulated as a result of the transportation of the vegetal matter by water. According to the latter theory the fragments of plants have been carried by streams and deposited on the bottom of the sea or in lakes, in much the same manner as any other sediment would be carried, and allowed to settle to the bottom to build up strata which later become compressed into solid rock.

The evidence favoring the *in situ* or *autochthonous* origin of the deposit may be summed up as follows: (1) There are large accumulations of vegetal matter forming in swamps at the present time, some of which are on a scale approaching those which gave rise to coal seams of considerable extent. (2) The purity of the coal, or its relative freedom from mineral matter, suggests the collection of the vegetation in swamps rather than in deposits where it has been transported with other sediments. The periods of high water when the greatest amount of vegetation is transported are also those when most mineral matter is carried. (3) Numerous tree trunks with their roots firmly embedded in the underlying clays occur in the coal seams and in some cases the rootlets pierce fragments of buried wood in the clays. (4) The topographic conditions under which the large coal fields formed were like that of a land surface near the critical level (that is, near sea level), and a slight sinking of the land would permit the sea to transgress over it or, in basins removed from the sea, permit sediment to be washed into the basin from adjoining lands. (5) Old soils on which the trees grew lie beneath the seams in some places. (6) Such an accumulation could not take place in the open sea and estuaries are not in very favorable locations because of the immense amount of mud usually carried into them. (7) The arrangement of various portions of plants with respect to one another is not, as a rule, that of transported material. (8) The lenses of cannel in

[1] For summary of theories see "The formation of coal beds," by J. J. Stevenson. Proc. Amer. Phil. Soc., Vol. 50, pp. 1–116, 1911.

bituminous coal, or bands along the upper surface of bituminous coal seams, indicate patches of open water in swamps where spores would collect in great quantities rather than deposits forming part of an ordinary sedimentary formation. (9) The lenses and bands of "mineral charcoal" suggest higher portions in the swamp exposed to weathering and more extensive rotting than that undergone by the remainder of the vegetation in the swamp. If this charcoal represents the remnant of burned wood transported to open water as some have suggested, it could scarcely have the distribution which it usually has in the coal seams.

In favor of the *transportation* or *allochthonous* theory there are the following factors: (1) Enormous quantities of timber are rafted down streams in regions of virgin forest. (2) In some modern deltas beds of peat and brown coal have been found. (3) Coal beds are often associated with marine fossils which occur in the strata immediately above or below the seams of coal. (4) The rocks associated with the coal are distinctly sedimentary and the seams appear to constitute a part of a regular sedimentary series, usually showing an increasing fineness in the particles of sediment in the rocks underlying the seam as the seam is approached. (5) The fire-clay beds commonly found beneath coal seams are not necessarily clays on which forests grew, as formerly supposed, because similar clays have been found in marine formations unassociated with coal. (6) It is difficult to determine in many cases whether a stump of a tree is located where it grew or whether it has been transported to its present location and gradually buried by clay or sand which settled around it, while resting upright on the bottom of the basin. (7) Trees have been found with their tops headed downward. (8) The large numbers of spores grouped in the coal in some seams indicates their ability to float about freely and collect in masses. (9) The presence of fish remains in coal, especially the cannel coal of England, suggests considerable open water where the vegetation accumulated. (10) It would appear to be difficult for large trees to root in such an enormous depth of vegetal matter as that necessary to produce some of our thickest coal seams.

Historical Sketch of the Development of the Theories for the Origin of Coal

As early as the year 1778 Buffon[1] recognized the vegetal origin of coal and gave it the name *charbon de terre*, the term still frequently used in France. In the same year Von Beroldingen[2] very intelligently expounded the *in situ* origin of the vegetation in a peat-bog, its burial and its transformation from peat into the various types of coal. These writers were followed by many who had more or less hazy and highly theoretical views regarding the origin of coal. Even Darwin seemed to regard some of the coal beds as bituminous distillations from vegetal matter capable of migration from one rock horizon to another.

In the year 1831 MacCulloch published a work[3] in which he supported the peat-to-coal theory. He pointed out that the plants forming the peat were of terrestrial type and that they grew in swamps. Three years later Marinnott recognized the prevalence of an underclay with coal seams but stated that there could be no genetic connection between the coal and the clay because he failed to find roots in the clay. A little later Buckland[4] described how the vegetal matter was transported and he expounded the *drift* origin of the deposits. Although Witham[5] had probably made the first microscopic studies of coal in 1833 it remained for Link[6] to extend this work five years later and apply his results to the origin of coal. He concluded that coal was developed from peat because of the presence of various vegetal materials in it and that the vegetation accumulated in place. In 1841 Logan[7] stated that from his observations underclays were

[1] Buffon, L. de., Histoire naturelle, générale et particulière Sonnini Edn. Tome 9 me, Paris.

[2] Von Beroldingen, Franz., Beobachtungen, zweifel und Fragen, die Mineralogie überhaupt und insbesondere ein natürliches Mineral System betreffend; Erster Versuch, 1778.

[3] MacCulloch, J., A System of geology with a theory of the earth, Vol. II.

[4] Buckland, W., Geology and mineralogy considered with reference to natural theology, Phila. 1837.

[5] Witham, H., On the Internal structure of fossil vegetables found in the carboniferous and oolitic deposits of Great Britain, 1833.

[6] Link, F., Uber den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen Untersuchungen. Abhandlungen d. k. Preuss, Akad. Wiss. Berlin pp. 33–34, 1838.

[7] Logan, W. E., On the character of the beds of clay lying immediately below the coal seams of South Wales. Proc. Geol. Soc. London, Vol. III, 1841.

characteristic of all coal seams and that from the presence of *Stigmaria* in these clays the vegetation must have consisted chiefly of this species which grew on these clays. Two years later Rogers[1] published a very comprehensive statement of the results of his observations. He concluded that the Pittsburgh seam extends over at least 14,000 square miles and that when isolated areas where it occurs are added the total area could not be far from 30,000 square miles. He stated that he failed to see how beds of such extent and purity could have been formed from drifted vegetation and he believed that they were formed in swamps on great marginal plains subjected to gradual subsidence. He considered the underclays as very common and *Stigmaria* as almost always present in them, often preserving its fibrous processes. Another important point that he brought out was that the roof was different from the sole formation and that the roof sandstones showed evidence of strong currents.

From a study of Russian coals Murchison[2] favored the *drift* theory but he also preferred the *in situ* theory for some of the English coal seams where the underclays represent old soils on which Sigillaria grew. Le Conte[3] favored the *in situ* theory because of the purity of the coal and the preservation of the delicate portions of the vegetal matter. He believed that the vegetation grew in bogs around the mouths of large rivers. Jukes[4] favored the *drift* theory because of the "rock faults" and frequent alternations of barren rock and coal. He believed that the materials were sorted on the basis of specific gravity. On the other hand Dawson concluded from a microscopic study of coal and an extensive investigation of the South Joggins area in Nova Scotia that the vegetation grew where it was accumulated because of the numerous examples of standing trunks, and the roots in place. He considered that the coal consisted chiefly of bark and similar materials with spores as a very minor constituent. He also regarded the irregularities in the floor of the seams as characteristic of the inequalities seen in swamps of the present day. Steven-

[1] Rogers, H. D., An inquiry into the origin of the appalachian coal strata, bituminous and anthracite, Repts. of Amer. Ass. of Geologists and Naturalists, Boston, 1843.

[2] Murchison, R. I., The geology of Russia in Europe and the Ural Mountains, Vol. I, p. 112, 1845.

[3] Le Conte, J., Lectures on coal. Ann. Rept., Smithsonian Inst., p. 131, 1858.

[4] Jukes, J. B., The South Staffordshire coal field. Memoirs Geol. Survey of Great Britain, 2 ed. London 1859.

son,[1] Andrews,[2] and Newberry,[3] as a result of their studies in Pennsylvania, Ohio and West Virginia strongly support the *in situ* theory. Dana considered that the coal was made up of all parts of the trees and that it accumulated in marshes. Mietzsch[4] was opposed to the transport theory and described the sunken forests near the coast off Rotterdam as illustrative of buried peat deposits found *in situ*. In 1878 Lesley[5] described how cannel lenses occur in pools on the mass of vegetation which formed the coal seam and pointed out the significant fact that if the coal deposits were not formed in a continuously subsiding area it would have been impossible for the many thousands of feet of shallow water deposits filling the Appalachian trough to have been laid down beneath the Coal Measures. He also believed that the underclays represented the finer particles of rock sorted out of the coarse sandstones and conglomerates and concluded that where underclays were thick they should therefore be associated with extensive sandstone strata. Grand'Eury[6] seems to have favored a sort of combined *in situ* and *drift* theory as he believed the vegetation collected, suffered considerable decomposition, and was then washed from the land into the standing water where it was buried. He regarded the mineral charcoal as wood dried in the air. An objection was raised to the *in situ* theory because the roots of the trees do not penetrate the coal but spread out over it at the top of the seam indicating that they cannot exist in a mass of decomposing vegetal matter. It is well known, however, that this objection is overcome by observation of a modern peat-bog or swamp. Grüner[7] objected to the transportation of the vegetal matter chiefly because of the freedom of the coal from mineral sediment. He was strongly in favor of accumulation in place.

In the year 1883 Von Gumbel[8] published an excellent discussion

[1] Stevenson, J. J., The upper coal measures west of the Allegheny Mountains. Ann Lyc. Nat. Hist. N. Y., Vol. X, p. 226, 1873.

[2] Andrews, E. B., Geol. Survey of Ohio. Vol. I, Pt. I, 1873.

[3] Newberry, J. S., Geol. Survey of Ohio, Vol. II, Pt. I, 1874.

[4] Mietzsch, H., Geologie der Kohlenlager, 1875.

[5] Lesley, J. P., Second Geol. Survey of Pa., 1878.

[6] Grand'Eury, Memoire sur la formation de la houille. Ann. des Mines Ser. 8, Tome I, 1882.

[7] Grüner, L., Bassin houiller de la Loire, 1882.

[8] Von Gumbel, C. W., Bertrage zur Kenntniss der Texturverhaltnisse der Mineralkohlen. Sitzungs d. Math. Phys. Klasse k. b. Akad. Wiss., Vol. 13, p. 113, 1883.

of his microscopic and field observations. He treated fragments of coal with potassium chlorate, nitric acid and later with ammonia. He then washed them with absolute alcohol, thus employing a system very similar to that used in recent years. He showed that even the "stove" coal is made up of the various fragments of plant débris, some of which are much more easily decomposed and much less durable than others. He concluded that different varieties of coal may result because of differences in the kinds or parts of plants, because of differences in chemical and mechanical conditions, or in the external conditions during transformation. He first used the terms *allochthonous* and *autochthonous* respectively to designate accumulation by transportation and accumulation in place. He regarded the interstratification of coal and distinct sediments as a strong factor in favor of those who support the *drift* theory but he felt that other evidence, — especially the similarity between vegetation in modern coastal swamps, subject to submergence by the sea, and the peat deposits which gave rise to the coal, — substantiated the autochthonous origin of the coal.

As a champion of the *drift* theory probably no one man has produced more convincing evidence in its favor than has Fayol,[1] a mining engineer, who made elaborate observations in the basin of Commentry in central France. He further supported some of his conclusions by laboratory experiments and as a result of his work a number of men were led to accept his opinions, among them the well-known French scientists, A. de Lapparent and B. Renault. He considered that the vegetation grew on high lands surrounding a deep lake and was washed into this body of water where it was deposited in a delta along with sandstones and conglomerates. The distinct delta deposits, the presence of abundant fish remains in associated shales, and the presence of trees with their tops headed downward are all taken as distinct evidences of the transportation of the vegetation. Many of these arguments are successfully refuted by Stevenson[2] who later studied the area and who claimed that nothing but a series of cloudbursts could tear the vegetation from the surrounding lands if it were as dense as necessary to produce the coal seams under discussion in

[1] Fayol, H., Terrain houiller de Commentry. Saint-Étienne. Livre Premier, Lithologie et Stratigraphie, 1887.

[2] Stevenson, J. J., The Coal basin of Commentry in Central France. Ann. N. Y. Acad. Sci. XIX, p. 161, 1910.

the 17,000 years postulated by Fayol for this operation. Stevenson believed that the vegetation of this coal basin accumulated *in situ*.

Gresley[1] regarded coal as of *drift* origin and based his conclusions largely upon observations in the Pittsburgh seam of the Appalachian province. He claimed that there are two slate partings in this seam from $\frac{1}{4}$ to $\frac{1}{2}$ inch thick separated by 3 to 4 inches of coal and occurring over about 15,000 square miles. These contain no *Stigmaria* and the underclay of this seam over large areas is a calcareous mud without *Stigmaria*.

One of the strongest supporters of the *in situ* theory was Potonié.[2] He describes a core 750 meters long from the upper Silesian coal measures in which there are at least 27 beds of coal each with an underclay carrying *Stigmaria*. He also describes a fossil swamp in the Miocene formations near Senftenberg which has given rise to brown coal and in which several generations of forests have grown and left their stumps rooted in the vegetal matter. His valuable observations on modern fresh-water swamps, such as those in Sumatra, have also helped a great deal in clarifying our ideas on ancient peat-producing swamps. He has suggested the following terms for organic deposits[3]: Kaustobioliths, or combustible rocks of organic origin, which are divided into Sapropelic deposits or those composed of animals and aquatic plants such as cannel coal and oil shales; and humus deposits which include all ordinary coals.

In reviewing the literature on the subject of the accumulation of peat it is found that the majority of writers favor the autochthonous or *in situ* theory, but there are many scientists of note who favor the opposite view. Among living geologists the former theory is most generally accepted and it is particularly well demonstrated in the discussions of White[4] and his colleagues, although White accepts the *drift* theory for some lesser deposits. On the other hand, Jeffrey,[5]

[1] Gresley, W. S., The slate binders of the Pittsburgh coal bed, Amer. Geologist, XIV, p. 356, 1894.

[2] Potonié, H., Ueber Autochthonie von Carbonkohlen-Flotzen und des Senftenberger Braunkohlen-Flötzes Jarb. d. k. Preuss. Geolog. Landesanstalt, 1895.

[3] Potonié, H., Die Enstehung der Steinkohle und der Kaustobiolithe überhaupt wie des Torfes der Braunkohle des Petroleums u. s. w. 5th ed., 1910.

[4] White, David, and Thiessen, R., The origin of coal. U. S. Bureau of Mines, Bull. 38, 1913.

[5] Jeffrey, E. C., The mode of origin of coal. Jour. of Geol., Vol. XXIII, 1915, p. 218. Also, Petrified coals and their bearing on the problem of the origin of coals. Proc. Nat. Acad. Sciences, Vol. III, p. 206, 1917.

the paleobotanist as a result of his extensive microscopic studies is a strong advocate of the *drift* theory, perhaps in a somewhat modified form. His conclusions are based very largely on the abundance of spore remains, thus suggesting accumulation of the vegetal matter in open water, as in cannel coal.

The writer believes that the majority of our coal seams are undoubtedly autochthonous in origin as most of the evidence supports this theory. Owing, however, to the strong arguments advanced and supported by both schools on this subject he agrees that some of the less extensive deposits have been allocthonous, especially the lens-shaped seams of limited extent occurring in lacustrine and estuarine formations of the delta type.

Discussion of the Theories of the Origin of Coal

(1) **The development of peat in bogs, marshes, and swamps.** *Peat-bogs.* — At the present day a vast amount of peat is being formed in small lakes and bogs, particularly in the cooler, wet climates and in

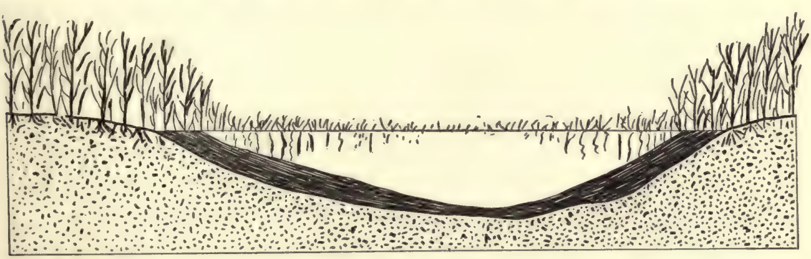


FIG. 18. — Diagram illustrating the formation of peat in a bog and the extension of the larger trees over the peat deposit.

the regions which have been glaciated and where drainage is therefore poor.[1] The depth of the peat may vary from a few inches to 50 feet but the detached areas covered by it are comparatively small and while a peat-bog may serve to demonstrate how vegetal matter accumulates in considerable quantities it is in no way comparable in extent to the great bodies of vegetation which must have given rise to our important coal seams. These peat-bogs generally begin with a pond or a small lake varying from a few hundred feet up to a mile or more in diameter. The development of the peat begins with the growth and partial decay of a fringe of plants around the border of

[1] Davis, C. A., The origin of peat. U. S. Bur. of Mines, Bull. 38, pp. 165–186, 1913.

the lake. The first plants to develop are usually the pond weeds and water lilies. These are followed by the bulrushes and beyond them the floating algae live in the deeper water where they do not reach the bottom. As this vegetation grows and dies, season after season, a deposit of peat develops along the shore and as it grows higher the plants mentioned gradually shift their relative position farther out from the shore and toward the center of the lake (Fig. 18). In the course of time a growth of sphagnum or "peat-moss," a large grayish-green or whitish moss, extends outwards over the peat deposit and this is followed by small trees of several species, chiefly the conifers; including the tamarack and spruce. As the peat becomes more and more firm, larger and larger trees will be supported and deciduous trees such as the white birch may partially replace the conifers. In time the lake may be completely filled up and the area overgrown by small timber.

As the peat develops several zones may be observed in the deposit. A very dark, heavy, dense peat forms at the bottom and lighter-colored, more fibrous layers occur as the surface is approached. Scattered through these layers there may be trunks of trees more or less altered. These trees grew around the border of the lake and were killed at times of high water, or they may have been blown down or otherwise killed and they then became imbedded in the peat. In seasons when the water is low and the surface of the bog stands above the water-soaked level the vegetation may suffer considerably more decomposition, or dry rot, than in other seasons and all but the more resistant portions of the material will be destroyed. This may, if carried sufficiently far, give rise to mineral charcoal. In wet seasons when the water is high, a much smaller degree of decomposition occurs and a much greater proportion of the vegetation is preserved so that alternate bands with varying composition result.

Marshes: In addition to the peat bogs there are in various parts of the world large areas without trees, where peat forms a shallow deposit covering a water-soaked land surface, but where standing water is not usually present except in the wet seasons. These areas are found chiefly in the frigid and temperate zone, but they may also be found in the tropics. In the colder regions the peat consists mostly of sphagnum, but in some places rushes and grasses may form a considerable part of the plant growth. The Arctic tundra is one type of

such deposit. In the warmer climates cane-brakes and "tule" marshes represent this type of peat development.

Fresh-water swamps: Interesting as the peat bogs and marshes may be in illustrating various ways in which peat may develop, they cannot be regarded as the sources of the peat which gave rise to im-

FIG. 19. — Cowhouse Run, Okefinokee Swamp, Ga. (Photo by Francis Harper.)

portant deposits of coal. There is sufficient peat in the temperate regions of the world today to form large amounts of coal, if it were concentrated into coal seams, but no single bog or marsh known would supply sufficient peat to make a large coal seam, although Geikie states that one-seventh of Ireland is covered with peat bogs and in Allen alone, 238,500 acres are covered with peat to an average depth of 25 feet.

There are, however, other deposits of peat forming at the present day in both temperate and tropical regions, which much more nearly

represent the kind of accumulation of vegetation which gave rise to extensive coal seams. These deposits are forming in immense fresh-water swamps such as the Dismal Swamp of North Carolina and Virginia and the Sumatra swamp in the East Indies. Large swamps of similar character are believed to exist in tropical Africa and South America. From descriptions of these swamps it is apparent that the idea so commonly held that peat can scarcely form in warm climates and that modern deposits of peat are practically restricted to the

FIG. 20.—Scene in a cypress bay, Okefinokee Swamp, Ga (Photo by Francis Harper.)

cooler regions of the earth is not correct. In fact there are deposits of peat in these swamps much more nearly approaching large coal seams in extent than anything found in the cooler regions. If there be an abundant rainfall on poorly drained land and a type of vegetation capable of very rapid growth, the wastage of peat due to higher

temperature may be offset by the greater rate of growth in tropical or sub-tropical climates.

According to Shaler[1] the inundated portion of the Dismal Swamp is about 38 miles north and south by 25 miles east and west. The

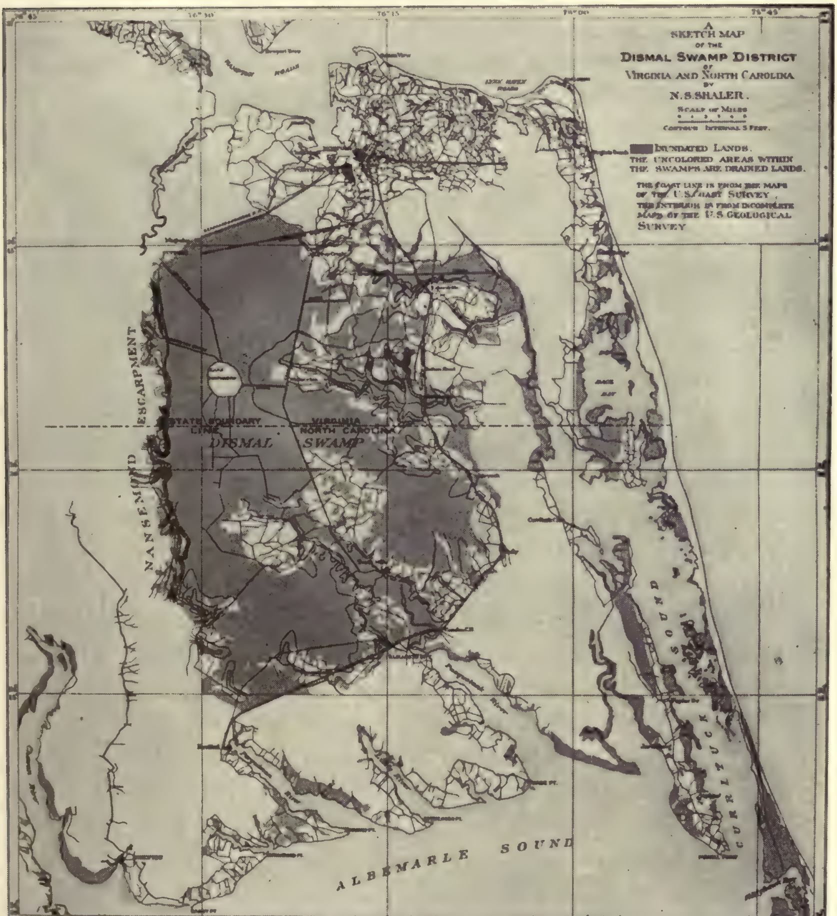


FIG. 21.—Map of the Dismal Swamp. North Carolina and Virginia, showing the relation of the swamp to the coastal plain. (After Shaler, U. S. Geol. Survey.)

swamp which was apparently extending its borders before man began to drain and cultivate portions of it is now considerably smaller than

[1] Shaler, N. S., Geology of the Dismal Swamp District of Virginia and North Carolina. U. S. Geol. Survey, Tenth Ann. Rept., Pt. 1, pp. 313–339, 1888–9.

it was originally. Osbon places the total area of this swamp originally at 2200 square miles with 700 now drained.[1] It lies on the coastal plain and represents the largest continuous swamp area of the many scattered over this plain between the Appalachian Mountains and the sea (Fig. 21). The rocks underlying the swamp are mostly stratified marine sands with some lime beds probably of Pliocene age. The surface is slightly rolling or billowy but the differences in elevation are small and on the whole the area approaches a level surface from 5 to 25 feet above the sea. The geological events which have given rise to the present relief are outlined by Shaler as follows: (1) A subsidence leading to the formation of the Pliocene plateau. (2) Elevation permitting erosion of the plateau. (3) Subsidence permitting deposition of non-fossiliferous sands. (4) Elevation permitting carving of surface. (5) Subsidence and formation of the Nansemond escarpment. (6) Reëlevation and development of valleys of streams to present depth. (7) Sinking now taking place.

From this description it is seen that this swamp stands near the *critical level* in much the same way as the swamps of the coal measures must have been situated and that a slight change in elevation might produce dry land or a transgression of the sea. There are areas of open water in this swamp, such as Lake Drummond, which might represent the more extensive areas of open water in the coal measure swamps in which the spores collect and produce canneloid, thus giving rise to lenses of cannel coal. This lake is gradually filling up with peat by the encroachment of the vegetation. There are other areas which are never completely submerged and which are comparatively dry during the greater part of the dry seasons. These exposed areas would illustrate those on which mineral charcoal would form because of more extensive rotting resulting from exposure (Fig. 22).

The vegetation in this swamp varies with the amount of water present. The higher levels are usually occupied by pines such as the common southern pine. The lower levels are mainly occupied by three species of trees, the Taxodium, or bald cypress, the juniper, and the black gum. The juniper occurs on the land which becomes fairly well dried during the dry season. The other two may grow in areas continuously covered with water if the water does not rise too

[1] Osbon, C. C., Peat in the Dismal Swamp, Virginia and North Carolina. U. S. Geol. Survey, Bull. 711-C, 1919.

high, as they develop knees, or arched roots to aid in keeping themselves above water.

The fallen trees, the spores, the leaves, and other plant débris are continually falling into the water in this swamp and building up a layer of peat which has been estimated at 1 to 20 feet in thickness. Osbon has estimated that 1500 square miles are covered to an average

FIG. 22.—Lake Drummond, Dismal Swamp. (Photo by Shaler, U. S. Geol. Survey.)

depth of 7 feet and that the total available peat in this swamp is about 672,000,000 tons. This peat if turned to coal would be sufficient to form a seam from about 1 inch to 20 inches in thickness and it would have many of the characteristics of coal seams as we are familiar with them today. The ash content is quite satisfactory. If the sinking of this area continued very slowly, the living vegetation would be destroyed and opportunities would be offered for the collection and preservation of a large amount of vegetation. It might become buried by the encroachment of the sea and the deposition of sediments over the vegetation. Submerged stumps in the valley of the Pamlico River, in this area, indicate that in comparatively recent time, geol-

ogically speaking, submergence has occurred. On the other hand a slight uplift of the land surrounding this basin might cause large quantities of mud, sand, or gravel to be washed into the swamp and form partings in the resulting coal when a new swamp formed on top of this rock.

The other large fresh-water swamp of which we have some definite knowledge is one on the island of Sumatra described by Potonié.[1] It is said to cover about 312 square miles. The peat deposit reaches a thickness of 9 meters or nearly 30 feet in this swamp and it is made up of a mixture of logs and plant débris of all sorts. There is a stagnant, tea-colored blanket of fresh-water over the peat, which makes an efficient preserving fluid for the materials which fall into it. The ash content of the dried peat is 6.39 per cent. This material if compressed into bituminous coal should produce a seam nearly 3 feet thick, as the lower layers of peat have already undergone considerable change and they are dense and compact.

That many swamps and forests have become buried beneath marine and fresh-water deposits is well demonstrated by Stevenson[2] in his article on "Buried Forests." An interesting example is also mentioned by Mietzsch[3] who says that off Rotterdam two bogs, 5 meters and 6 meters thick, are separated by a bed of clay 4 meters in thickness. Some of the trees are still standing and they are of types which inhabited the adjacent lands centuries ago. Another of greater antiquity was described by Potonié from the Miocene and previously mentioned in this chapter. In these illustrations we seem to have abundant evidence of the efficacy of fresh-water swamps in producing coal deposits under proper climatic and topographic conditions.

Mangrove swamps: There are also certain salt and brackish water swamps, which occur along the sea coasts and in which the trees are mostly mangroves. They are known as mangrove swamps. These are found in the tropical or semi-tropical regions and some of them are of considerable extent. They may be seen in northern New Zealand, Ceylon, Cuba, Florida, and many other countries (Fig. 26).

[1] Potonié, H., Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt, 5th ed., pp. 152–160, 1910.

[2] Stevenson, J. J., The formation of coal beds, Pt. II, Proc. Amer. Phil. Soc., Vol. 50, p. 626, 1911.

[3] Loc. cit.

The long stilt-like roots raise the trunk above the water and among these roots the vegetal débris collects. They sometimes extend a short distance from the shore where the water is shallow and while considerable peat forms in such a swamp, so far as the writer's observations go, there is always a large amount of sand mixed with the peat owing to the tidal currents and storm-waves which wash it into the swamp. This type of swamp never seemed very favorable for

FIG. 23. — Portion of Dismal Swamp in which peat is covered with water. (Photo by Shaler, U. S. Geol. Survey.)

the formation of extensive bodies of peat. These trees may, however, grow farther back from the sea and even in fresh-water swamps where conditions are more favorable to the formation of purer peat deposits.

(2) **Drifted vegetation and delta deposits.** — The *drift* theory for the collection of vegetation giving rise to coal deposits has many supporters who naturally invoke processes now operative on the earth's surface to substantiate their arguments. They can point to a few cases where coal is being formed or has been formed in undoubted delta deposits in comparatively recent time considered from the

geological standpoint. In an article describing briefly the artesian wells at Venice, Italy, Degousée[1] mentions lignite beds which were pierced in drilling for water. He states that the sea is very shallow in the Gulf of Venice for a long distance from the shore. At a depth of 60 to 70 meters and above the real artesian bed ascending water is struck which is so charged with hydrogen carbide that the water is intermittently thrown above the surface with great violence. This gas is said to burn well but nothing is recorded regarding its relation to the lignite beds. In all the wells bored several beds of lignite in sand and clay were passed through. Unfortunately we have no detailed data concerning the thickness or number of these seams. There were in the lignite fragments of wood sufficiently preserved to be identified.

Reference is frequently made in literature to the enormous amount of timber floating down the Mississippi River and the rafts of driftwood, several miles in length, which years ago blocked the channel of the stream. Conditions as they are at present, in the cleared and cultivated valley of that river, make, however, a poor parallel to the conditions prevailing when the country was covered with virgin forest, as a vastly greater proportion of mineral matter is being carried than would have been carried then. A closer parallel to the conditions prevailing when coal was being formed may possibly be seen in some of the rivers in northern Canada where many streams flow through regions covered with virgin forests and peat bogs. One is impressed, for example, by the vast quantities of timber which descend the streams to James Bay every spring (Fig. 27). Owing, however, to the great variation in size of the fragments and the difference in the rate at which they become water-logged and sink, or float out to sea, there seems little opportunity for this material to collect into any extensive bodies of peat on the sea bottom. One of the main difficulties in the way of its producing coal is the fact that when most plant débris is carried in flood periods there is always more than the normal quota of mineral matter taken along.

In an effort to obtain definite information regarding the proportion of plant débris carried by streams and thus support his arguments

[1] Degousée, M. J., Note sur les alluvions formant les lagunes venitiennes, et sur les puits artésiens de la ville de Venise. Bull. de la Societé Geologique 2 Série, Tome 8, pp. 481–4, 1850.

for the *drift* theory for the basin of Commentry, central France, Fayol[1] stretched a wire screen of one centimeter mesh across a stream known as the Baune. This was done in the month of January and it collected 502 grams in 2 minutes, or 1.5 grams for each cubic meter of water passed through. He also made certain laboratory experiments in a small body of water to determine the action of vegetal matter in sinking to the bottom and of mixing, or separating itself

FIG. 24. — Timber undergoing partial decay in the Dismal Swamp. (Photo by Shaler, U. S. Geol. Survey.)

from the sediment which was carried into the body of standing water with the plant materials. He found that the roots were among the first materials to sink. Many stems remained in an upright or inclined position on the bottom and the plant débris formed deposits varying from practically pure vegetal matter to those highly mixed with mineral matter.

According to this writer, the basin at Commentry, in Carboniferous

[1] Fayol, Henri. Terraine houiller de Commentry, Livre Premier, Études sur le terrain houiller de Commentry, p. 397, 1887.

time was occupied by a fresh-water lake surrounded by high lands. Streams entered the lake with sufficient gradient to move large boulders, some of granite in the conglomerate underlying the coal reaching a cubic meter in volume and suggesting for them a glacial origin. As a parting in the famous Grande Couche, a seam reaching a maximum thickness of 20 meters, there are 8 meters of conglomerate with some boulders half a meter in diameter. Another peculiar

FIG. 25. — Destruction of trees by high water in the Dismal Swamp. (Photo by Shaler, U. S. Geol. Survey.)

feature of these coal deposits is the presence in the conglomerates of the Coal Measures of pebbles of coal and abundant grains of coal in the sandstones showing that older coal beds had been broken up by erosion.

Some of the other evidences of the *drift* origin of the coal at Commentry are trees with their trunks in an inverted position, and the presence of abundant fossil fish in the associated rocks. The occurrence of inverted tree trunks cannot, however, always be regarded as conclusive evidence of drift origin because one may often see trees in a swamp broken off by the wind and embedded, head down, in the

peat. Their chances for preservation are, however, not great unless covered with clay or sand, since most of them project above the water-level. The presence of upright trunks and stumps on the other hand cannot be regarded in many cases as definite evidence of growth in place because a stump floating into a body of water will most likely settle to the bottom in an upright position, owing to the weight of the roots if they be present, or the greater weight of the big end of the trunk, when water-logged, if roots be absent. There are stumps in the Coal Measures at St. Étienne, France, with a number of roots penetrating the underlying rocks but it is impossible to determine whether the stumps are in place or whether they floated to their present position and became buried by sediment (Fig. 28). If, however, the unbroken rootlets are found in their proper position and roots are found piercing fragments of buried wood this would be regarded as proof of their growth *in situ*. Such conditions are found in many of the great coal fields.

Some writers attach importance to the relative number of upright stumps and trunks in the coal and in the adjacent conglomerates, sandstones, and shales. This circumstance cannot carry any particular weight in the argument because it is evident that these rocks are capable of supporting the trunks in this upright position and they were buried quickly; whereas the soft, yielding peat would permit them to be easily crushed down flat by the superincumbent load of rock or vegetal matter. Fayol observed that in the Commentry basin 99.5 per cent of the stems were flat in the coal and 0.5 per cent vertical or inclined. In the sandstones 70 per cent were flat and in the conglomerates 60 per cent.

The fact that so much better plant remains are found in the shales and "coal balls" than in the coal itself is due to the soft, pliable peat, which gave rise to the coal, squeezing and creeping under the weight of the overlying rocks and to partial decomposition of the vegetal matter because of longer exposure destroying original structures. In many cases the tree will rot out in the sandstone or shale leaving perhaps traces of the bark and this space becomes filled later by sand or clay which is squeezed into it, thus giving a stone-cast of the tree. The rock in these casts often differs from the rock surrounding them because it has been squeezed up from a lower stratum or down from a higher stratum than the one holding the cast. In

some of these casts, mineral matter from solution may be deposited where the wood has disappeared, giving more iron oxide, calcium carbonate or similar mineral than is found in the surrounding rock.

The sequence of conglomerate, sandstone, shale, and coal beds in varying succession argues strongly for the *drift* theory as it would appear that in so many cases there was almost complete assortment of sediments on the basis of specific gravity and rate of settling. Further, the accumulation of vegetation to such a tremendous depth

FIG. 26. — Mangrove swamp creeping out over the sea on coast of New Zealand. (Photo by E. S. Moore.)

as that necessary to produce 50 or 60 feet of anthracite might seem to some most easily accounted for by supposing that the material was transported and dumped into a body of water because there would be little opportunity for trees growing in this mass to root in anything but peat. It has been shown, however, that many of the larger trees which occupied the swamps were specially equipped with roots adapted to an existence near the surface of wet peat deposits and they were no doubt supported by the extensive matting together and interlocking of the roots of the forest trees. It is known that trees of considerable size can subsist at the present day on thick deposits of peat and it seems much easier to explain the accumulation of such great masses of peat, so free from mineral matter and requiring such

long periods to form, in a swamp free from sediment than in open water where every season large quantities of mud or silt are likely to be carried and spread over it during floods.

The Sargasso Sea:[1] One other phase of the *drift* theory may be mentioned. It has been suggested that the great mass of plankton floating on the ocean might segregate in the eddies in the ocean currents and, sinking to the bottom, build up peat deposits which would be well preserved. This mass would be made up of great quantities

FIG. 27. — Drifted timber along the Metagami River, James Bay basin, Canada. (Photo by E. S. Moore.)

of very small, low types of floating plants associated with sea-weed and other forms of plant life which would be carried about on the ocean surface. While it is true that some material is collecting in this way at the present time anyone familiar with ocean travel knows that coal beds were never formed in this way because there is not sufficient material being deposited. Deep-sea dredgings have failed to show any accumulation of plant material worth mentioning. Other convincing evidence opposing this theory is the presence of coarse littoral sediments so frequently interbedded with the coal seams, indicating that these sediments are shallow water or land formations and not deep-sea deposits.

[1] Mohr, F., Geschichte der Erde, 1886.

Rate at which Peat Accumulates

The rate at which peat forms in any given region will depend upon the rate of growth and proportional rate of decay. The nature of the vegetation will have a great influence on the rate of growth as some trees grow so much faster than others on an area partially or entirely covered with water, the condition essential for the preservation of the vegetation after it is grown. Coarse vegetation will naturally build faster than fine material but there are certain types of the finer plant débris which build at a fairly rapid rate owing to the fact that the proportional shrinkage is not so great as in the coarse débris and the material is being supplied to the bog every year. If we consider for example the spores of plants which fall every spring and float about in the open bodies of water until they sink we will find that a large amount of this material collects every year and goes to build up canneloid, which later forms cannel coal. The writer has seen, while traveling in the late spring through the northern woods of this continent, such quantities of spores and pollen grains from the birch, poplar, and related trees floating on the water of the small lakes and ponds that it was impossible to obtain water fit to drink. There are often so many of these green globules in the water that in places it becomes thick with them. They collect in bands and little ridges along the shore where washed up by the waves. It can be easily understood how vast quantities of these spores collecting in patches of open water in large swamps might produce lenses of cannel with the other coal. Modern microscopic investigations of coal tend to show that spores are very widely distributed through all coal and that owing to their resistance to decay they form a prominent constituent of the coal. Another constituent which resists decay and is prominent in many coals, especially those formed chiefly from coniferous trees, is resin. This has been observed in considerable proportions in microscopic studies.

The soil will have some influence but after a thick layer of peat has developed the plants gather most of their sustenance from the air and water. It seems probable that the feldspathic rocks observed as so common in coal measures in various countries of the world may have furnished more than the average amount of potash to the vegetation, which was able to root in the soils of those days, and thus produced conditions favorable for growth.

The climate plays a large role in the deposition of peat because a wet, uniform climate will produce much more vegetation in a given time, other things being equal, than a climate where growth and preservation are limited to certain seasons of the year. The rate of decay in a warm climate will be greater but this is largely offset by a good water blanket for the fallen plants. The latter is possible only if the climate be uniformly wet throughout the year. If there be long, alternately wet and dry seasons, there will be little peat formed, unless the climate be cool, no matter how much rain falls.

There is no satisfactory way of computing the rate at which peat accumulated in the coal-forming periods. We can only judge the rate approximately by considering the amount of peat which forms at the present day in a given time and it is only in a few areas that definite information can be obtained regarding the rate of formation of modern peat deposits. Where a forest is cut away or where peat grows over a road or other cultural feature whose age is known, quite accurate data may be obtained regarding its growth. Lesquereaux considers that in the Jura of Switzerland, peat has formed to a depth of 18 to 20 inches on an area which has been cut over within 50 years. Geikie[1] gives quite a number of cases where the rate of growth is well established. In the valley of the Somme, 3 feet of peat has developed in 30 to 40 years, and on a moor in Hanover 4 to 6 feet has grown in about 30 years. Near Lake Constance a layer 3 to 4 feet thick has required only 24 years while among the Danish mosses 10 feet required 250 to 300 years for its deposition.

In summing up the data concerning the rate of growth of peat Ashley[2] states that under the most favorable conditions 1 foot may form in 5 years, and that 1 foot in 10 years is a fair average maximum. In the larger and deeper basins the rate is slower and in any case the newly formed peat soon contracts to only a fraction of its original bulk. Lesquereaux considers that a foot of peat at the surface shrinks to $\frac{1}{8}$ foot at depth in the bog. By taking into account the specific gravity of the peat at the surface and at depth, it is possible to arrive at an approximate figure for the amount of old peat formed from the surface layer. It is generally agreed that approximately

[1] Geikie, A., Text-book of geology, 2nd ed., p. 443, 1885.

[2] Ashley, G. H., The maximum rate of the deposition of coal. Econ. Geol. Vol. 2, pp. 34–47, 1907.

1 foot per century is a fair average rate for the development of old compressed peat.

The Amount of Coal Derived from a Given Amount of Peat

Having considered the rate at which peat forms we may take up the question of the approximate rate of the formation of coal. No definite figures can be obtained on this subject but a number of valuable observations have been made. Renault[1] has decided after ob-

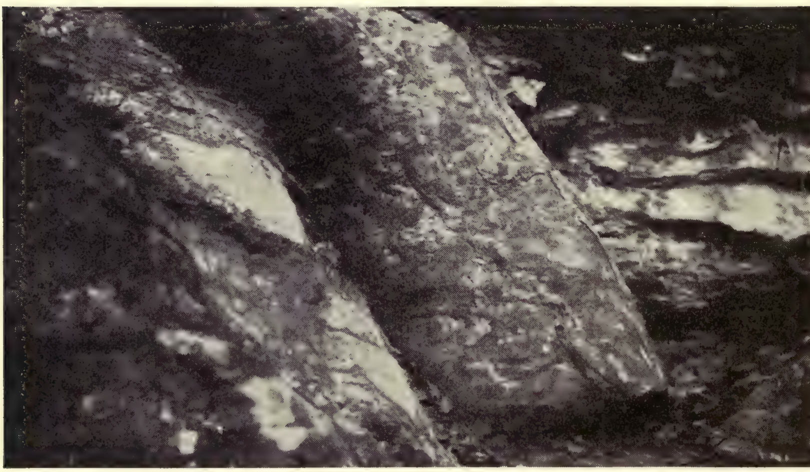


FIG. 28. — Upright trunk in Coal Measures at St. Étienne, France. Broken at base. (Photo by E. S. Moore.)

serving carefully the shrinkage of stems of trees in passing from wood to coal that the loss is from eleven-twelfths to twenty-nine-thirtieths of the original. This is for the change to bituminous coal of the Commentry basin in France. Ashley[2] from calculations made on the relative specific gravity, and on the loss of moisture and other constituents, concludes that 3 feet of old peat would form 1 foot of bituminous coal such as that in the Pittsburgh seam, and, as a rule, about 20 feet of vegetal matter will form 1 foot of coal. In deducing his figures Ashley has also used other interesting examples such as the shrinkage in the vegetal matter which formerly filled a small, deep basin and now forms a thin lens-shaped layer of coal on the bot-

[1] Renault, B., Sur quelques microorganisms des combustibles fossiles, Bull. de la Soc. de l'industrie minérale, 3me série Tome 13–14, 1899–1900.

[2] Ashley. Loc. cit., p. 42.

tom of the basin. He cites another case where two basins were connected over a low ridge and, considering that the basins were filled to a given level so that the peat could connect over the ridge, an approximation may be reached regarding the relative amount of coal formed on the ridge and in the basins from a mass of peat reaching a given level.

If a foot of old, compact peat forms in a century and it requires 3 feet of this peat to form a foot of bituminous coal it will require three centuries to form a foot of coal and three thousand years to form a seam 10 feet thick.

Various attempts have been made to express the change from wood to coal by chemical formulae but they are unsatisfactory because the formula given for cellulose will not represent the chemical composition of all the material entering peat, and it is difficult to write a chemical formula properly expressing the composition of a coal seam. There is almost no end to the formulae which might be written. Renault[1] gives the following to illustrate the change from wood of Cordaites to homogeneous coal:

$$\underset{\text{Cellulose}}{(C_6H_{10}O_5)_4} = \underset{\text{Bituminous coal}}{C_9H_6O} + \underset{\text{Marsh gas}}{7CH_4} + \underset{\text{Carbon dioxide}}{8CO_2} + \underset{\text{Water}}{3H_2O}$$

Parr's formulae[2] for lignite and bituminous coal are:

$$(1)\quad \underset{\text{Cellulose}}{5(C_6H_{10}O_5)} = \underset{\text{Lignite}}{C_{20}H_{22}O_4} + \underset{\text{Marsh gas}}{3CH_4} + \underset{\text{Water}}{8H_2O} + \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Carbon monoxide}}{CO}$$

$$(2)\quad 6(C_6H_{10}O_5) = \underset{\text{Bituminous coal}}{C_{22}H_{20}O} + 5CH_4 + 10H_2O + 8CO_2 + CO$$

These formulae are valuable in showing the relative proportions of the various constituents of the wood which are supposed by these investigators to be lost but they cannot be taken too literally as representing the changes which have taken place.

[1] Renault, Loc. cit., p. 299

[2] Parr, S. W., Illinois Geol. Survey, Bull. 3, 1906.

The Topographic Conditions Prevailing During Coal-forming Periods

On examining the topography of any of the continents as they existed prior to and during the deposition of the vegetation giving rise to the great coal deposits, it is found that extensive, low swampy areas were very characteristic. The coal-forming periods invariably followed periods when shallow, continental seas, which were gradually filling up, had spread over considerable areas of the continent. These

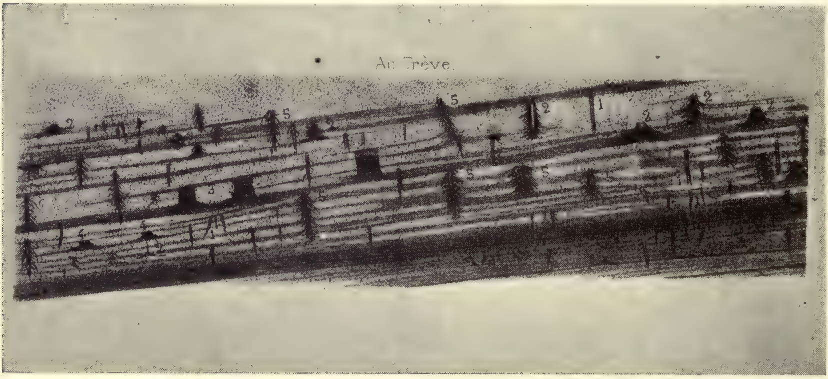


FIG. 29. — Section at Treve, France showing numerous stumps in Coal Measures. (After Grand 'Eury.)

seas gradually retreated leaving great expanses of low land, poorly drained and ideal for the development of swamps on a large scale. The conditions must have been closely parallel to those now found on our great coastal plains along the Atlantic Ocean and the Gulf of Mexico. In the eastern part of North America the deposition had been predominantly marine previous to the Carboniferous period. During this period the land over most of this part of the continent began to emerge finally from the sea, never again to become an area of extensive marine deposition, although the western portion of the present continent continued to be covered with the sea. With the emergence of this great area there was a differential rise of the area bordering on the Atlantic and lying between the Atlantic as it then existed, and a long northeast-southwest sound on its westward side, known as the Appalachian trough. This trough was being filled with sediments from the land masses forming Appalachia on the east,

the pre-Cambrian areas to the north, and the Cincinnati arch to the northwest. These land masses continued to be the source of clastic sediments, for the area occupying the old Appalachian trough became practically filled with sediments at the beginning of the Carboniferous period, presenting the aspect of an extensive coastal plain. This great flat area was subject to very gentle warpings, probably the forerunners of the larger buckling movements which later produced the Appalachian Mountains at the close of the coal-forming period. This area was so near sea level that a slight rise brought it into the condition of dry land or a small subsidence put it below the ocean just as minor changes cause the Atlantic coastal plain of the present day to rise above or fall below the sea.

In the larger of the depressions formed by warping of the strata the swamps giving rise to the more extensive coal seams such, for example, as the Pittsburgh seam originated. In many of the depressions slow subsidence was constantly going on as these basins were being filled up with vegetal matter and sediment but it seems probable that the conditions can be best accounted for by frequent small elevations of the surrounding land and consequent relative sinking of the low areas. In some cases the conditions even permitted encroachment of the sea, the destruction of forests, and the deposition of limestones and other marine deposits over the accumulated vegetal matter. Much of the sediment found associated with coal seams consists of feldspathic sands indicating incomplete decomposition, as if the materials composing the rock had been swept off a land surface where rocks were disintegrating. These products of disintegration might have been carried off to the basins owing to change of climate, or elevation of the land on which they were lying, causing greater activity of water. These materials could be derived from the disintegration of granitic rocks and they could be rapidly transported to an area of deposition without being completely sorted or waterworn if streams became very active owing to increase in velocity due to increase in gradient or volume of water.

The general absence of extensive erosional features in the measures during Carboniferous time indicates that there was a general subsidence in progress and that the swampy areas were seldom raised sufficiently above the sea to permit much erosion of the formations carrying the coal. They were areas of deposition rather than erosion.

The red beds of the later Permian indicate a drier climate than that which had prevailed during the Carboniferous and the coal-forming process had practically ceased when the larger movements producing the Appalachian Mountains occurred.

An examination of the conditions in the western part of the continent at a later period shows that the conditions found in the east during the Carboniferous, (Mississippian and Pennsylvanian) were

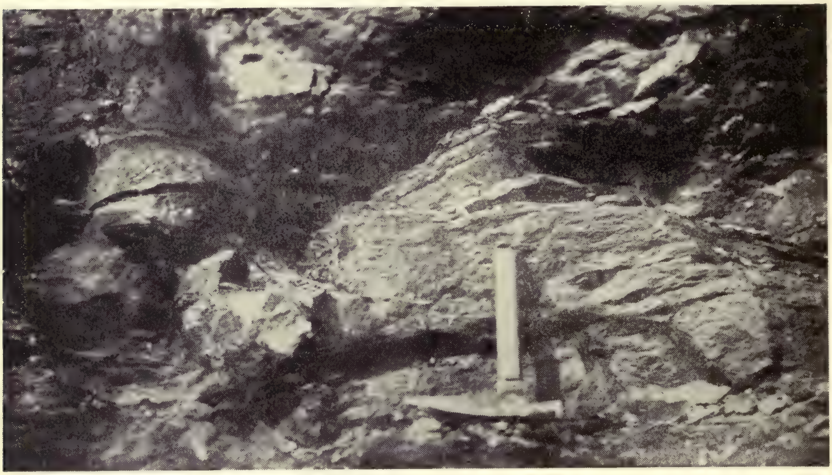


FIG. 30. — Upright trunk in Coal Measures showing roots descending into rock to right of the hammer. (Photo by E. S. Moore.)

practically duplicated in the west during the Jurassic and Cretaceous periods. During the former period a large shallow sea extended over the region now occupied by the Cretaceous and Tertiary coal deposits. This sea gradually withdrew from the land and conditions became favorable for extensive swamp development. The coal-forming processes ended with the elevation of the Rocky Mountains as it did in the east with the rise of the Appalachians. An examination of other continents will reveal a similar close relation between the topographic conditions and the development of extensive coal-bearing formations. The essential features are base-leveling of the higher areas with a consequent aggrading and leveling up of the lower ones, and a general slow subsidence of the areas of peat deposition.

The Origin of Underclays

Various names have been applied to the clays underlying coal seams such as the "sole," "seatearth," and "mur." Some seams have no distinct underclay and some even lie on granite, schist or other igneous or metamorphic rocks. Beneath others the floor of the seam is conglomerate or coarse sandstone, and limestone underlies a few beds. In many seams the change from coal to barren rock is abrupt while in others there is carbonaceous shale or black slate lying next to the coal indicating a gradual transition from the coal to the rocks free from vegetal matter. The shales, being less porous, are more likely to have partly preserved vegetation in them than the sandstones are, because the latter permit access of oxidizing water which decomposes the vegetal matter and leaves no carbonaceous deposit. The change thus appears more abrupt at the contact with sandstone than it really was.

Underclays are so abundant in certain coal fields that some early writers, like Logan, regarded them as a universal accompaniment of coal seams. They are almost everywhere present under the seams of some of the English and American fields of Carboniferous age and they have been regarded by some writers as inseparably connected genetically with the seams. Many of these clays are fireclays and they are of great economic importance. They seldom show good stratification which may be at least partly explained by their plastic property, permitting them to be squeezed and kneaded under pressure until the bedding was lost. It is also observed that a layer of rock which has been penetrated by innumerable roots usually loses its laminated character.

The unstratified character, the bleached appearance, and the common occurrence of *Stigmaria*, or roots in these clays has led many observers to regard them as old soils on which the vegetation forming the coal seams grew. It is well known from observation that the roots of plants will bleach the rocks they penetrate and these underclays bear a certain resemblance to the muds under some modern peat-bogs and swamps. It is also well known, however, that modern peat does not grow only on such soils but it may be found on sands, marls, or almost any kind of rock. It is therefore evident that underclays are not essential to the growth of luxuriant vegetation and the question may then be asked whether the vegetation is essential to

the development of the underclays. Some writers have gone so far as to claim that where coal is not found above the fireclay it has been removed by erosion, but such a sweeping statement does not seem to be justified because fireclays have been found in marine deposits unassociated with coal deposits of any kind. Most of those clays are, however, stratified and laminated.

If the drift theory were to be accepted for the accumulation of the vegetal matter these clays should represent a deposit of the finest and most completely assorted mineral sediment deposited in quiet water just before the lighter vegetal matter settled to the bottom. In that case, however, they should show more stratification than they do. Arber[1] suggests that they are marine and brackish water oozes deposited in estuaries like the black oozes of the nipa and mangrove swamps of the present day. If this be so, it is hard to understand why they are found only in their present position with reference to the coal. If coal be deposited in accordance with the *in situ* theory then these clays may have been the finer material which filled the basin in which the swamp occurred and the lack of stratification resulted from the growth of the plants upon it and later movements in a semi-plastic mass.

There is one other possibility. If the statement of Mietzsch holds good that living Lycopodiaceae have from 22 to 26 per cent of clayey matter in their ash and the ancient types of these plants had a similar proportion, may not the decay of vast quantities of such plants on the floor of a swamp, before there was sufficient water over the vegetal matter to prevent decay, have produced a deposit such as the underclay? Some efforts have been made to compare the composition of the ash of the coal with that of the fireclay but this has not proved to be an entirely satisfactory means of settling the question. The clay in any case is mineral matter and there is always more or less of this in coal, carried in by wind and water from surrounding lands, and while it may be similar to that in the plants it is independent of the composition of the ash of the wood. It is probable that some clays are at least partly chemical sediments.

There is much need of further information regarding these interesting and valuable rocks. It seems very probable that the clays were deposited as part of a normal series of sediments and that

[1] Arber, E. A. N., The natural history of coal, p. 91, 1912.

the growth of plants helped to destroy the stratification and to extract certain of the soluble salts; but the plants were not absolutely necessary for the formation of the clay nor was that kind of clay necessary for the growth of the vegetation as demonstrated by modern swamps and peat-bogs.

Climatic Conditions

Concerning the climate of the coal-forming periods there is some difference of opinion among paleobotanists. They are our chief judges in this discussion because we are dependent mainly upon the plants of those periods for indications of climatic conditions. There is one feature, however, concerning which there is unanimity among all the best authorities, and that is that the climate was uniform over great areas of the earth's surface. This is demonstrated by the fact that the same genera and some of the same species of plants of Carboniferous age are found distributed over both hemispheres from the tropical to the polar regions. A similar condition prevailed again in Jurassic and Cretaceous times. As to the cause of this uniformity little is definitely known. It has been suggested by some geologists and botanists that this condition was due to a greater amount of carbon dioxide in the air than there is in normal times and Chamberlin[1] has described in detail how its presence might be brought about. Other factors which might aid in producing this uniform condition are the relation between sun and earth in position and distance and changes in the distribution of land masses in the sea, permitting warm ocean currents to reach the polar regions and melt the ice.

There is also little doubt concerning the humidity of the atmosphere during the coal-forming periods. This is necessary for the growth of such enormous quantities of plants in order that they may give rise to coal. Humidity and uniformity in climate are rather closely related. Further, if we accept the *in situ* theory for the origin of coal, sufficient water to cover the fallen vegetation is essential for its preservation and the warmer the climate the more the water required.

As to whether the climate in the Carboniferous and other great periods of peat formation was hot is a debated question among paleo-

[1] Chamberlin and Salisbury. Geology, Vol. III, p. 432, 1906.

botanists. Arber[1] claims that there is nothing in the Carboniferous flora so far as known to prove that it was tropical in character, as luxuriant forests may be found today in temperate regions and the large cells of the plants do not necessarily indicate tropical conditions. White[2] believes that the climate was humid, uniform and mild, being generally either tropical or sub-tropical. Some evidences of these conditions are the similarity in character between many of the plants now found in tropical swamps and those found in coal formations. The absence of growth rings in the trees indicates uniformity in seasons and the wide distribution of almost identical floras indicates uniformity in climate over wide areas of the globe. The large leaves and fronds, and the large cells with thin walls indicate rapid growth. The stomata are protected in grooves on the under sides of leaves of many plants and subaerial roots are found on many species. The seeds show provision for flotation and delayed fertilization. The presence of tree ferns, palms, and cinnamon trees in the Tertiary coal deposits suggests tropical, or at least sub-tropical conditions.

There is one rather peculiar association of plants known as the Gangamopteris, or Glossopteris flora, which in Permian time spread widely over the Southern Hemisphere. It is different from the other coal-formation floras because of its close association with glaciation. It is found in Australia, India, South Africa, South America, and to some extent in Russia, where Glossopteris and Gangamopteris are abundant in the vicinity of Moscow.

In Australia the Permo-Carboniferous, or possibly more strictly, the Permian system, forms a very thick group of rocks containing extensive coal seams, which are of fresh-water origin and which in most cases show evidences of autochthonous origin by the presence of roots in the underlying clays. This group also contains thick beds of tillite showing that glacial conditions were prevalent at that time and that there were at least two great interglacial periods. A condensed description of these rocks taken from David's work is as follows:[3]

[1] Arber, E. A. N., The natural history of coal, Cambridge University Press, p. 70, 1912.

[2] White, David, The origin of coal, U. S. Bur. of Mines, Bull. 38, p. 68, 1913.

[3] David, T. W. E., British Ass. Adv. Sci. Handbook for Australia, p. 257, 1914. See also Süssmilch, C. A. An introduction to the Geology of New South Wales, p. 93, Sydney, 1914.

	Thickness Ft.
1. Acid granites of New England	
2. Upper or Newcastle coal measures; with 35 to 40 feet of workable coal. Glossopteris predominates over Gangamopteris. Dadoxylon abundant	1500
3. Dempsey Series; Barren fresh-water shale	2200
4. Middle coal measures; with 20 feet of workable coal	500–1800
5. Upper Marine Series; with marine fossils and glacial erratics	6400
6. Lower or Greta coal measures; with about 20 feet of workable coal. Gangamopteris predominates over Glossopteris	100–300
7. Lower Marine Series; with marine fossils. Basalts and tuffs. Glacial beds 300 feet thick at base	4800

At Bacchus Marsh, Victoria, there are four beds of tillite in a formation 2000 feet thick. These glacial beds have been correlated with the Dwyka conglomerates of South Africa. In one place Gangamopteris occurs with a local coal seam in the upper part of the Lower Marine series, in fresh-water deposits.

So far as known the *Glossopteris* flora does not occur in the typically Carboniferous strata which reach 20,000 feet in thickness in Australia, nor is *Lepidodendron* found in the Permo-Carboniferous although prevalent in the Carboniferous and upper Devonian. No doubt the great change in climate was too severe a test for Lepidodendron and related plants and they disappeared during the glacial conditions.

Although there were two glacial periods associated with the coal seams of the Permian, there is no evidence that there was a sudden change in climate and that the Glossopteris and Gangamopteris flora lived under frigid conditions. These glacial epochs were separated by long periods of time and when it is considered that during the apparently much shorter interglacial periods of the Pleistocene in America such trees as the pawpaw (*Asiminia triloba*) and the osage orange (*Maclura arantiaca*), now found only considerably farther south, grew at Toronto, Canada,[1] it seems probable that Australia may still have had a reasonably mild climate during the formation of the important coal seams of Permian age.

The Transformation of Vegetal Matter into Coal

It is generally recognized that when vegetation changes to coal it passes through two stages, the first being known as the biochemical and the second as the dynamochemical stage. As these terms indicate,

[1] Coleman, A. P., Interglacial fossils from the Don Valley, Toronto. Amer. Geol. Vol. XII, p. 86, 1894.

the first process is due chiefly to the action of bacteria and other low forms of life and the second to geological forces capable of producing chemical and physical changes in the vegetal matter.

The biochemical process, or the first stage in coal formation. — When plants in a bog or swamp cease to grow, and fall, they are subject to attacks from bacteria and other low organisms. The most extensive investigations on this subject have been carried on by Renault,[1] the French scientist, who spent most of his later years

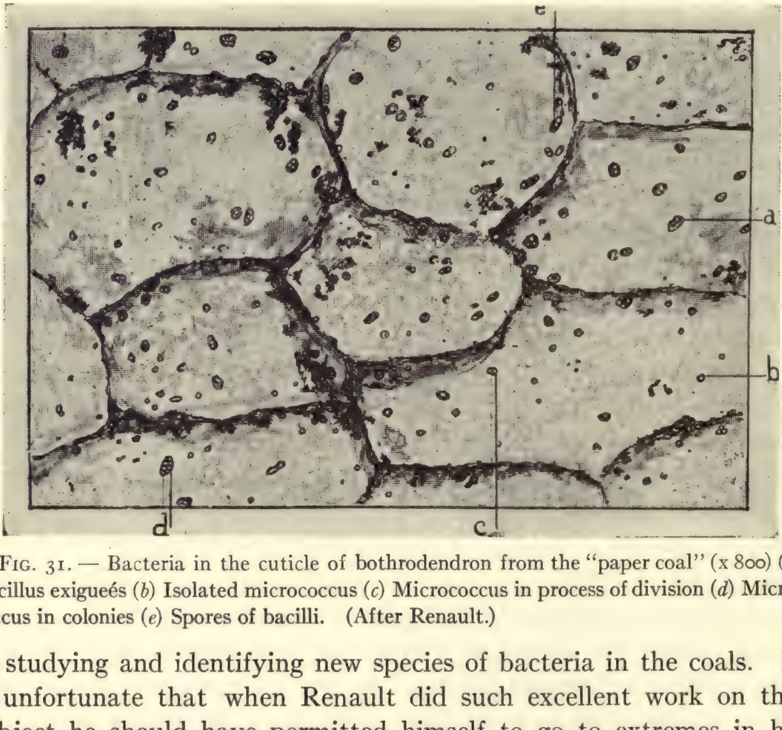


FIG. 31. — Bacteria in the cuticle of bothrodendron from the "paper coal" (x 800) (*a*) Bacillus exigueés (*b*) Isolated micrococcus (*c*) Micrococcus in process of division (*d*) Micrococcus in colonies (*e*) Spores of bacilli. (After Renault.)

in studying and identifying new species of bacteria in the coals. It is unfortunate that when Renault did such excellent work on this subject he should have permitted himself to go to extremes in his ideas of the prevalence and importance of these fossil organisms in the coal. Having had the privilege of examining his original slides the writer is convinced that many objects taken for bacteria were specks of mineral matter and in some cases, at least, crystallized organic matter. Similar conclusions have been reached by others who have investigated this subject. Renault has shown, however,

[1] Renault, B., Loc. cit. Also du rôle de quelques bactériacées fossiles au point de vue géologique. Congrès Géologique International, pp. 646–663, 1900.

that a great many bacteria have been sufficiently well preserved to be recognized and to show that they undoubtedly did a great deal to macerate the vegetal matter (Figs. 31 and 32). There have been recognized representatives of the living forms such as Micrococcus and Streptococcus in addition to many others. These forms were most active in the upper layers of the peat because the lower portions of the bog were so charged with organic solutions of ulmic, crenic and other acids resulting from chemical action that the bacteria could scarcely exist. Although no quantitative study has been made of this subject it is believed that their action extends to comparatively shallow depths.

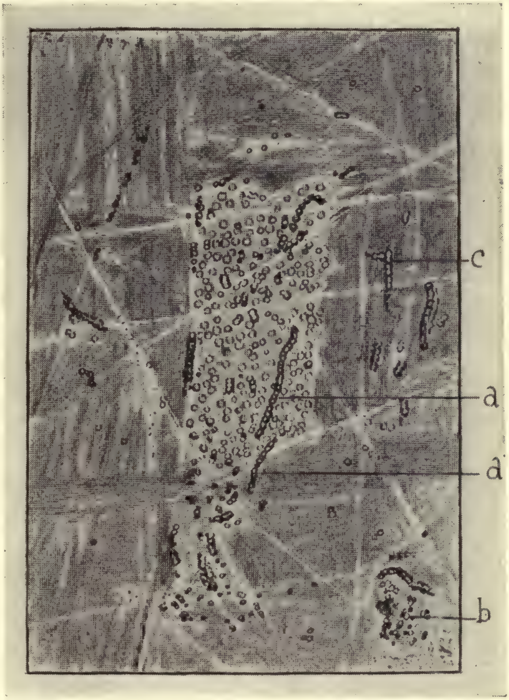


FIG. 32. — Chains of bacilli in coal of arthropitus (x 1200) (*a*) Chainlet of bacilli mostly diplospores (*b*) Group of arthrospores (*c*) Chain beginning to ramify. (After Renault.)

In addition to the bacteria there are many larger plants, especially the fungi, which help to produce chemical changes and aid in the maceration of the plant débris. Among these, mushrooms and related plants probably play an important role. The action in all cases seems to result in a change from the production of oxygenated hydrocarbon compounds of the living plant to a breaking up of these into such simple compounds as the oxides of carbon. When the latter compounds are formed the hydrogen must then be free to form simple compounds with carbon and with oxygen such as methane, and water.

In addition to the bacterial action being halted by acid compounds

resulting from their own action, it may be stopped by burial of the peat under layers of sediment or by mineral matter, deposited from solution, surrounding the plant débris. The latter action is well illustrated by the concretions commonly called "coal balls" found in many seams, or in the rocks overlying them. These bodies frequently contain perfectly preserved plant remains showing that the mineral matter must have sealed them up almost immediately after they fell.

The second stage in coalification: It seems to be generally admitted that biochemical processes are responsible for the early stages in the alteration of the plant débris as it changes to coal of any kind or even to old compact peat. There is a much greater divergence of opinion, however, regarding the processes which continue the alteration until different varieties of coal result. Since the greater number of observers consider that the second stage is produced almost entirely by dynamochemical action this stage in the process is very frequently discussed as if the dynamochemical were the only factor to be taken into consideration, but several other hypotheses have been advanced in opposition to the dynamochemical theory.

The various suggestions to account for the development of different varieties of coal from vegetal matter may be summed up as follows: (1) Differences in kinds of vegetation and differences in climates in different regions. (2) The length of time during which the vegetation has been exposed before burial by sediments. (3) Length of time since burial of the vegetation. (4) The depth of burial of the vegetation. (5) Action of heat from compression or from intrusions of igneous rocks. (6) Possibility of escape of volatile constituents after burial beneath sediments because of fractures or pores in the overlying rocks, and jointage in the coal seams. (7) The pressure resulting from compression of the seam during dynamic changes in the enclosing rocks.

1. Different kinds of vegetation and different climates. — An examination of the different varieties of coal, omitting special types like cannel, will show that they differ very little in their physical composition. They all, whether lignite or anthracite, contain light and dark bands, fragments of resin, spores, fragments of bark and other plant débris. This seems to indicate that they may have been derived from the same type of vegetation. Anthracite has not been

shown to contain a greater proportion of spores, resin or other portions of the plant than bituminous coal. It is well demonstrated that in an anthracite region a seam will be anthracite throughout and not in patches only like the cannel in bituminous coal seams. The following analyses will show that various types of trees are so nearly alike in chemical composition that it would be impossible to put them through the same geological processes and expect to get different kinds of coal from them.

Wood	Ash	C	H	N	Calorific power
Oak	0.37	50.16	6.03	....	4,620
Ash	0.57	49.18	6.27	....	4,711
Hornbeam	0.50	48.99	6.20	....	4,728
Beech	0.57	49.06	6.11	0.09	4,770
Birch	0.29	48.88	6.06	0.10	4,771
Fir	0.28	50.36	5.29	0.05	5,035
Pine	0.37	50.31	6.20	0.04	5,085
Cellulose	....	44.4	6.2	....	4,146

Table by Gottlieb. From Cellulose, by Cross and Bevan. Longmans, Green & Co.

Plant	C	H	O	N	Ash
1. Lycopodium dendroideum	47.11	6.39	41.85	1.40	3.25
3. Lycopodium complanatum	45.78	6.25	40.66	1.84	5.47
5. Equisetum hyemale	41.94	5.89	39.23	1.12	11.82
7. Asidium marginale	44.77	5.99	41.97	2.08	5.19
9. Cyathea caniculata	45.39	6.11	39.82	1.12	7.56
11. Cyathea caniculata	48.72	4.89	38.48	1.42	6.49

Analyses by G. W. Hawes.[1] Nos. 1, 3, 5 and 7 are average samples of the part of the plant above ground, including spores. Nos. 9 and 11 are tree ferns from Tahiti. No. 9 is an analysis of a section of the stem and No. 11 of the cortical part.

Analyses of coal derived from different genera of Carboniferous trees were made by Carnot and it can be seen that the differences in composition in coal from Lepidodendron, Cordaites or Ptychopteris are negligible, the maximum difference in carbon being only 2.66 per cent and in hydrogen 0.03 per cent.

The plant fossils were identified by Renault and carefully selected

[1] Hawes, G. W., On the chemical composition of the wood of acrogens. Amer. Jour. Sci. (3rd Series) Vol. 7, p. 585, 1874.

to obtain any differences in the coal which might be due to differences in the original vegetation.

It can be concluded that different types of plants cannot produce any material difference in the nature of the coal formed and that they have no particular bearing on the origin of anthracite. It is recognized, however, that different portions of the plant such as spores or resin, the latter of which may contain over 80 per cent of carbon, may form different types of coal if separated from the other plant débris and segregated in sufficiently large masses. There is, however, no evidence whatever that such has been the case in the formation of anthracite.

As for differences in climate producing any marked variation in the coal of different regions, there is no ground for accepting such a theory as all vegetation must be covered with water to preserve it. There is no great difference in the peat formed from trees in the tropical and temperate zones.

2. Exposure before burial. — It is a recognized fact that if wood be exposed to the air certain portions will decompose before other portions and there will be a relative increase in carbon and a decrease in hydrogen and oxygen. The wood usually decomposes first and leaves the more resistant bark and related tissues. To illustrate the change which occurs, the following analyses are quoted from Fayol's work.[1]

Carbon in bark of oak, 29.65 per cent; in sound wood 21.95 to 22.82 per cent; in the same tree, slightly decomposed, 24.75; more decomposed, 27.60; and rotten, 31.00 per cent. Analyses by Pollard of dark and bright coal from a seam in Wales show carbon in bright band 63.96, and in dull powder 77.17 per cent, and since the dull layers of mineral charcoal are generally thought to have originated through extensive rotting of the vegetation before burial these figures show that there undoubtedly may be considerable difference produced in the composition of the resulting material by more prolonged exposure before burial. When one attempts to employ this as a means of explaining the origin of the great deposits of anthracite it is useless, however, because these dull layers are present in bituminous coal also, and they are distributed throughout the anthracite seams in such a way as to indicate that they have no bearing on the anthracitic character of the seam taken as a whole.

[1] Fayol, H. Loc. cit., p. 171.

It has been suggested that the anthracite field of Pennsylvania owes its origin to longer exposure of vegetation laid down in the eastern part of the state than that deposited in the west because of a gradual migration westward of the coastal plain on which the plants grew. This assumption scarcely seems justified because it is probable that the swamp or swamps which gave rise to the Pennsylvanian coal deposits were spread pretty uniformly over the anthracite and bituminous areas at the same time. Further, the anthracite region being closer to Appalachia, the main source of supply for clastic sediments, it is probable that the vegetation was buried early in the history of these deposits In their studies of the South Wales anthracite deposits Strahan and Pollard state that no definite relation exists between the position of the anthracitized beds and the old shoreline.

3. Length of time since burial. — A general impression exists among many people interested in coal that the age of the coal has an important bearing on its quality. To a certain degree this assumption is correct, because, other things being equal, the older coals will be higher in the peat-to-anthracite scale than the younger ones, not simply because the vegetation was formed in any particular geologic period, but because the metamorphosing processes have had longer to work and the older rocks have as a rule been more deeply buried and subjected to greater pressures than the younger rocks. There are many examples on record where seams of Carboniferous age are still in the form of brown coal or lignite. Such a case is found in Western Australia where a small area of Permo-Carboniferous measures was faulted up and preserved from intense pressure. The coal is still brown coal, although practically all other Permo-Carboniferous coal in Australia is bituminous or anthracite In Russia brown coal occurs in the Mississippian, or Lower Carboniferous, while in the western states and Canada and in many other countries the Cretaceous and Tertiary coals, which are more typically lignite, have been altered to high-grade bituminous coal or even anthracite in local areas.

In connection with this discussion on the length of time since burial of the vegetal matter, the question of the length of time a bed of vegetation must be buried before it is changed to coal may be considered. We have very little definite information on this subject but there is a clue in the occurrence of coal pebbles in the rocks asso-

ciated with coal beds. Renault and Fayol[1] have discussed the coal grains and pebbles in the Coal Measures in the Commentry basin in France. That these are water-borne fragments of coal and not fragments of wood buried in the sandstones and conglomerates and later transformed into coal is indicated by the fact that they have not shrunk nor have they been deformed in shape as they would have been had they consisted of wood and been turned into coal after their burial. They must represent fragments of a deposit lower in the Carboniferous which had already changed to coal and been broken up by erosion.

In England there are also pebbles of coal high up in the Coal Measures which Strahan considers as distinct fragments of coal derived from an eroded coal seam lying a few feet below the Pennant grit which carries the pebbles. There is no older coal formation in the region which could urnish these pebbles. These examples indicate that coal must form quite rapidly from the vegetation.

As modern examples of wood changing to coal in very short spaces of time, a case occurring in the vicinity of Scranton, Pennsylvania, is cited by Moffat.[2]

A mine prop left standing and surrounded by mine refuse was subjected for about 30 years to high pressure from the roof and to high temperature from a mine fire, although the fire did not actually reach the prop. Different parts of the prop suffered varying degrees of alteration The lower portion was well preserved wood; about halfway up it was a little charred externally and above this it was turned into friable, soft charcoal. The upper part and especially the cap wedge, which had suffered from great compression and had been crushed down, was greatly altered and had a conchoidal fracture like anthracite coal, a jet black color, a bright glossy luster, and a specific gravity of 1.38. It burned with a feeble flame. Analyses showed that it contained: Moisture at 100°, 5.65; Volatile Matter, 43.05; Fixed Carbon, 51.00; and Ash, 0.30 per cent. It would appear that although heat aided this change the pressure was necessary to produce the coaly character, as distinguished from charcoal. The wood in this prop and wedge retained its structure very well.

[1] Op. cit.

[2] Moffat, E. S., Note on the formation of coal from mine timber, Trans. Amer. Inst. Min. Eng., Vol. 15, p. 819, 1886.

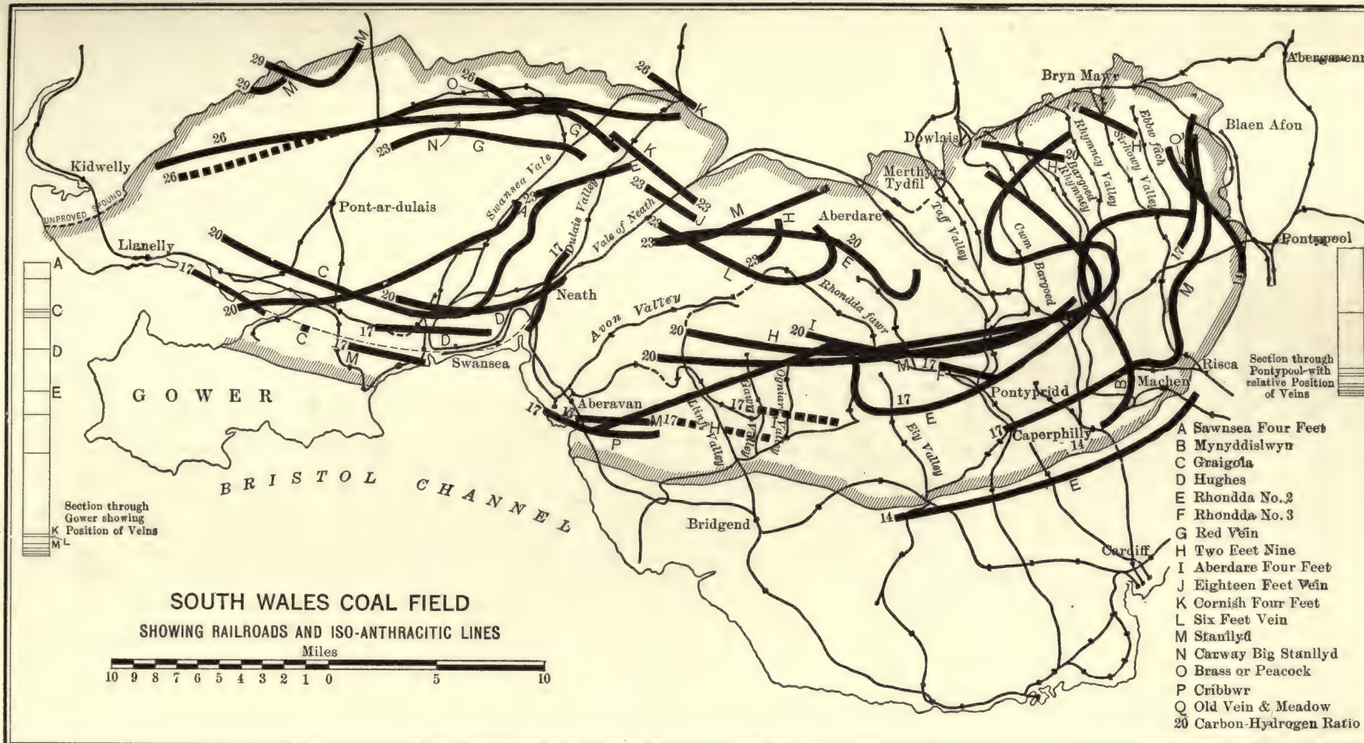


FIG. 33. — South Wales coal field showing a compilation of the iso-anthracitic lines for the various seams in the field. These lines strongly suggest structural contours. (From Strahan and Pollard.)

Daubreé[1] and Fremy have produced materials resembling coal from various woody constituents at temperatures from 200° to 300° C. It was found that woody fibers, as vasculose and cellulose, became black and brittle but retained their organization and did not fuse; while such substances as starch, sugar, gums, and chlorophyll became, when subjected to heat and pressure, black, brilliant, and insoluble like coal. The latter substances will also leave a coke. This may account for some of the differences between lignite and black lignite, or subbituminous coal, the one originally having more woody material than the other.

From all available evidence it would appear that coal may form in a very short time, geologically speaking, if conditions be favorable. The chief factors producing the change are heat and pressure.

4. Depth of burial. — The depth of burial is so closely related to the compression resulting from crustal movements that these two factors may be considered together. It should be pointed out, however, that there are few, if any, cases where it can be shown that the depth of burial alone was sufficient to produce anthracite, although it is such a generally recognized principle that the fixed carbon increases and the volatile matter decreases with depth in a series of seams that this principle is commonly known as the Law of Hill, after the man who expounded it. It has been stated by some writers that there is a definite relation between the depth of the seams and the anthracitization of the coal in the basin of Commentry in France, but this statement will not hold in all cases. Strahan[2] has pointed out that in the South Wales field the cover of not only the Palaeozoic rocks but also of the later rocks over the bituminous field is much thicker than that over the anthracite field. He states further, however, that in general the conclusion of De la Becke and Joseph that the lower seams in the anthracite field were more anthracitic than the upper was correct but this will not hold for all seams throughout the field. The chart of iso-anthracitic lines (Figs. 33 and 34) brings out clearly the relation between the various seams in this field. White[3]

[1] Daubreé, Études et expériences synthétiques sur le métamorphisme et sur le formation des roches crystallines, p. 72, 1860.

[2] Strahan, A., and Pollard, W., The coals of South Wales, with special reference to the origin and distribution of anthracite. Memoirs Geol. Survey, England and Wales, 2nd Ed., pp. 73 and 74, 1915.

[3] White, D., Op. cit., p. 126.

has pointed out that of 20 cases where two or more of these seams were vertically 100 feet or more apart the analyses show only one case where there was a downward increase of volatile matter. Two cases show no difference and the others show an average loss per 100 feet of descent of 0.6 per cent volatile matter. In American seams, out of thirty-four cases twenty-nine show an average decrease of 0.38 per cent volatile matter per 100 feet descent. Quoting from Van der Gracht, White states that at Helenaveen the decrease in the gas coal is about 0.53 per cent; at Helden in the coking coal about 0.8 per cent; at Baarlo about 0.62 per cent; and in Westphalia, 0.51 per

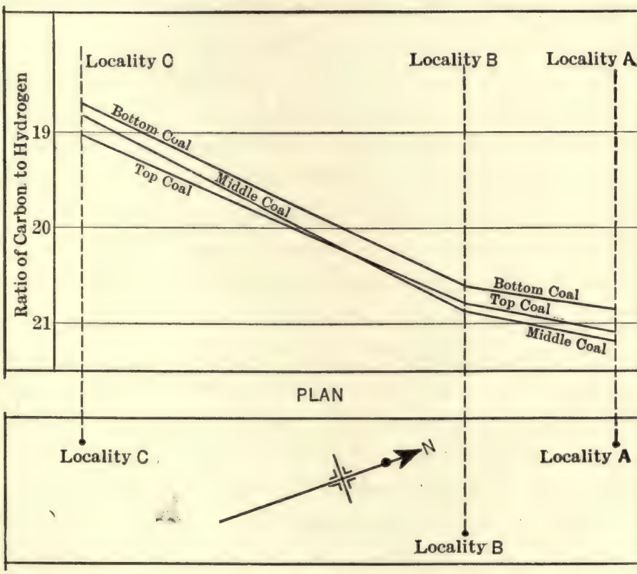


FIG. 34. — Relation between depth and the carbon-hydrogen ratios in three seams in the South Wales coal field. (After Strahan and Pollard.)

cent for gas coal and 0.71 per cent for coking coal per 100 feet. In Pennsylvania the depth of the anthracite seams cannot be taken as a criterion for the alteration which the coal has undergone but in some of the semianthracite areas of China there seems to be a more marked connection between the depth at which the seams lie and the degree of anthracitization There must, however, also be taken into consideration the factor of thrust, a subject which will be discussed later.

5. Effects of heat. — That heat from igneous rocks aided by the pressure which must be an accompaniment of intrusions can produce anthracite from bituminous coal has been proven beyond a doubt. In Colorado, Alaska, New Mexico, and in numerous countries, natural coke, anthracite, and other types of coal have been produced from bituminous coal by igneous rocks. The effects of igneous intrusions are, however, quite local and they have not been responsible for the anthracite in the great fields of South Wales and Pennsylvania. In the Cerrillos Coal Field of New Mexico, considerable anthracite, mostly of secondary grade, has been produced as a result of the intrusion of a great sill about 400 feet thick along the surface of a coal seam, but the effects extend only a comparatively short distance from the sill. As a rule there is some relation between the width of a dike or thickness of a sill and the width of the zone of coal affected, but this varies greatly. Usually the coal is not affected much beyond the width of the dike. It should be remembered in this connection that an igneous rock intruding coal will affect it much as it does other rocks which it intrudes. In some cases a dike or sill will scarcely metamorphose the adjacent rocks due to the fact it was almost cooled when it reached them or it may have had little hot gas or water to give off to attack the adjacent rocks. Some intruding rocks were hot and, carrying much hot gas and water, were capable of profoundly altering the surrounding rocks. As a rule acid rocks, such as granites and rhyolites, are capable of existing in the liquid condition at lower temperatures than the basic rocks like gabbros and basalts or traps, but they usually carry more liquids and gases and are, therefore, capable of producing more metamorphism at the temperature of intrusion than are rocks without these agents.

In 1869 Bevan[1] attempted to explain the origin of the South Wales anthracite as due to trap rocks but it has been shown that these igneous rocks were earlier than the coal seams. The formation of Pennsylvania anthracite has also been assigned to the heat of igneous intrusions but there are no intrusions worth mentioning in this coal field and those intrusions which do occur are Triassic in age and much later than the coal. Intrusions of the same age and character occur also in the bituminous field of Pennsylvania without appreciably affecting the bituminous character of the coal. It must be admitted

[1] Bevan, J. P., The geologist, Vol. II, p. 75, 1869.

that the influence of igneous rocks is very limited although nevertheless real.

6. Escape of volatile constituents through fractures and pores. — In order to explain the lack of anthracitization of coal in areas of intense folding and even where the temperature has been rather high, Campbell[1] has suggested that fractures such as joints or cleavage in the coal and adjacent rocks have been responsible for this process. He assumed that the transformation of one type of coal to another, higher in fixed carbon, was primarily due to heat although not necessarily to a high temperature and that time was a very important factor in connection with the results derived from heating. Pressure may be important in producing heat by compression and in aiding the driving off of the volatile constituents but unless there be a means of escape for these there cannot be much change in the coal either from compression or heating. The process may operate if the enclosing rocks be porous, and overlying coarse sandstones would be much more favorable than shales for the escape of volatile constituents. In support of this principle he cites the graphitic coal of Rhode Island as an example of coal carried to the extreme condition of carbonization because of extensive fracturing permitting escape of volatile constituents. The anthracite of Pennsylvania is more fractured than the bituminous coal, and the lignites of North Dakota and Texas are overlain by impervious clays. This hypothesis is said to apply equally well to all the coal fields studied in the United States.

Since there is no doubt that the coal changes to a higher carbon type by loss of gases Campbell's principle is perfectly logical but there are some limitations which should be kept in mind, and this may explain why some highly fractured coal has not been altered to a high carbon type. The extensive fracturing of a rock is evidence of yielding to stress, and the pressure which would have been exerted on the coal, if the rock had not been broken, is relieved by fracturing, with the result that both heat and pressure are lost. There is apparently a proper balance between the length of time the coal suffers pressure and the fracturing, because if the fracturing occurs too early in the process insufficient pressure may be exerted.

There are many coal seams which contain an abundance of gas

[1] Campbell, M. R., Hypothesis to account for the transformation of vegetable matter into the different grades of coal. Econ. Geology, Vol. I, p. 26, 1905.

which escapes by blowers or by oozing out during the mining operations. This coal is not necessarily lower in fixed carbon than other coal which does not give off so much gas during mining, because it has absorbed the gas in its pores. If the pressure be sufficiently great, the gas will be compressed and will remain in the coal, but in all cases where it cannot escape an equilibrium will be established between the volatile constituents attempting to escape and the compressed gas already given off. It is evident, however, that other conditions being equal less pressure will be required to raise the coal to a higher type if the gas can escape.

7. Effect of pressure. — Although there may appear to be many exceptions to the rule it must be generally recognized that anthracite and other high-carbon coals are characteristically found in regions of crustal disturbance the world over. Anyone reading the descriptions of coal fields will find that if any country contains anthracite it is invariably found in its mountains or disturbed areas, and this condition goes a long way towards establishing the thrust-pressure hypothesis for the origin of anthracite. This hypothesis has in recent years been worked out in great detail by White[1] for the United States, and he has shown that this is the most logical explanation for the devolatilization of coal in its second stage of development.

There are certain geological factors entering into a consideration of such a hypothesis which have not always been given due consideration. In almost any coal field there will be found a series of sediments made up of heavy, strong beds, such as sandstones or conglomerates, known as the *competent* beds; and others, such as coal and shale, which comprise the *incompetent* beds. When pressure is applied to these strata the incompetent beds yield and adapt themselves to the movements of the competent beds which are sufficiently strong to resist buckling. If the beds always lay perfectly horizontal, or the thrusts were always applied parallel to the bed and equally to all the competent beds there would be no important result. In such a heterogeneous column of strata, however, there are oblique thrusts and therefore movements of one rock over another in various directions, with the result that great pressures are exerted on the coal and the shale but the adjacent competent rocks have suffered very little

[1] White, D., Op. cit., p. 105; and, Some problems of the formation of coal. Econ. Geol., Vol. 3, p. 292, 1908.

deformation. This condition is well illustrated in Figure 63, where one formation is highly contorted but the rocks above and below show no effects of the pressure. Coal acts as a plastic mass in the early stages of its development from vegetal matter as illustrated by Figure 74, and it is then capable of accommodating itself to almost any shaped space without showing any trace of the movement. These structural principles may offer an explanation of the flat-lying anthracite seams in the Wyoming basin in Pennsylvania and in the coal fields of China. A highly fractured stratum is not always evidence of excessive pressure having been applied in that area but it is evidence that the pressure was relieved. It may not have done more than a small fraction of the work in devolatilizing the coal which it would have done had it been applied to a competent bed capable of withstanding that pressure and of transmitting it to the coal seam. A small amount of heat thus generated and held there for a long period of time, would devolatilize the coal.

If this principle be applied to the well-known anthracite fields of Pennsylvania and South Wales it is believed that it will explain most of the features. The Pennsylvania field lies in a highly disturbed area along the main limb of the anticlinorium forming the Appalachian Mountains to the southeast and the synclinorium forming the Appalachian Valley to the west of this field. There is, when considered on its broader lines, a marked difference between the complicated structure of this region and that of the comparatively simple structure of the bituminous field farther west. It is probable that this area suffered an unusual amount of compression where the mountains were developed and the fact that there are small, comparatively undisturbed areas within this region is no evidence that they did not suffer from intense thrust pressure. The thickness of the whole series of strata concerned in the great crustal movements must have also affected the pressure exerted on the coal seams although the seams lie near the top of the series. The strata were very thick, probably upwards of 25,000 feet in that region. The accompanying map of Pennsylvania showing the fuel ratios of the coal in various parts of the state illustrates the relation between the anthracite and bituminous areas and shows the gradation from one to the other (Fig. 35).

Turning to the South Wales anthracite field, so well described by

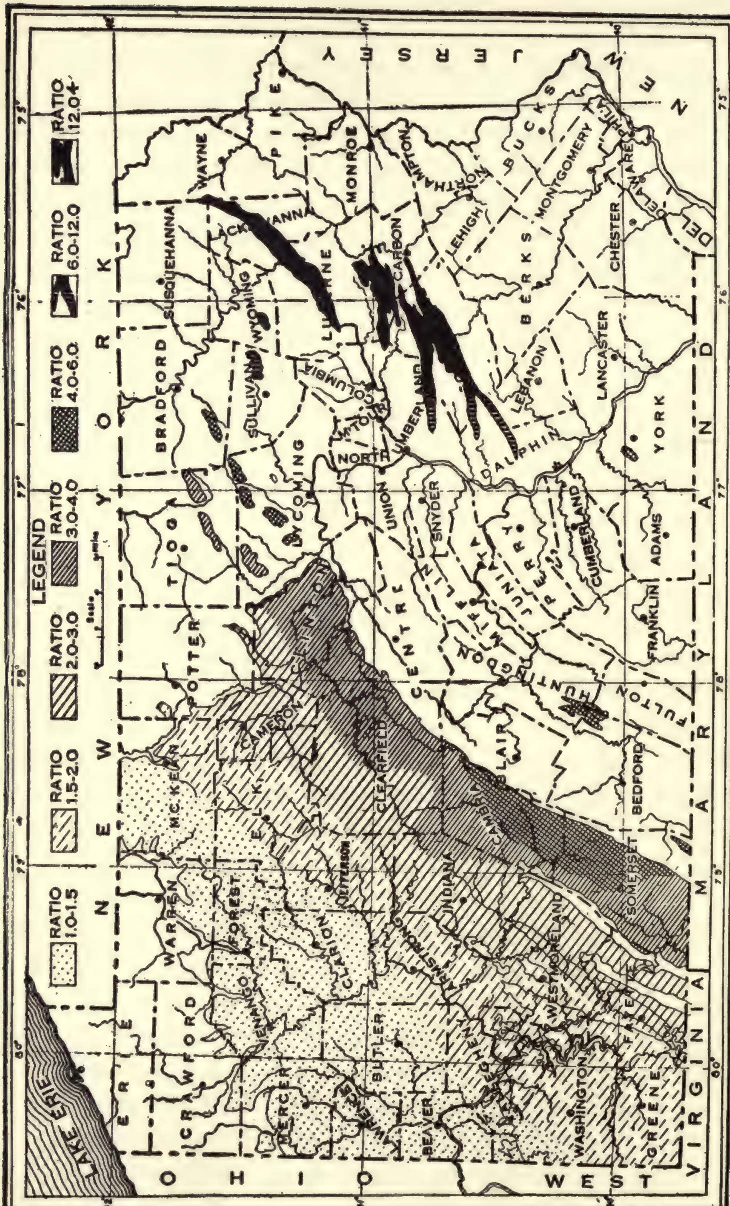


FIG. 35. — Map of Pennsylvania, showing distribution of coals by fuel ratios. (Pa. Geol. and Top. Com. Rept. 1906 — 1908). (Reprinted by permission from Ries' Economic Geology published by John Wiley & Sons, Inc.)

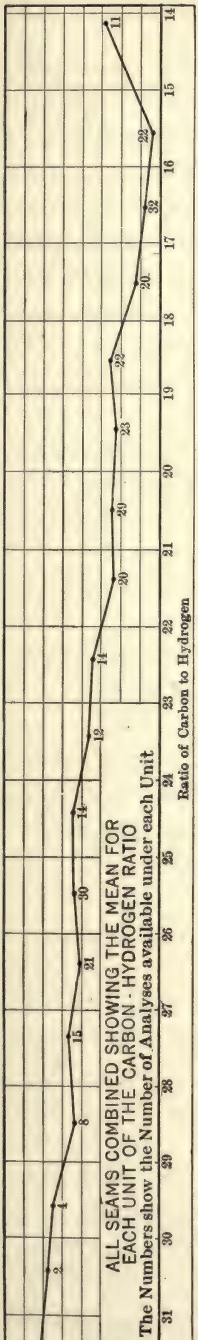


Fig. 36. — Relation between the ash content and the carbon-hydrogen ratio in the South Wales coal field. (After Strahan and Pollard.)

Strahan and Pollard,[1] a gradual change from anthracite to bituminous coal is found, but with the peculiar condition that there is a marked increase in the ash in the latter, a condition which would not be expected if part of the bituminous coal gave rise to anthracite by devolatilization. The ash content as indicated by all analyses available varies from about 1 per cent at the anthracite end to 6 per cent at the bituminous end. (Fig. 36.) Various explanations have been offered to explain this, such as differences in the original vegetation and differences in the extent of decomposition before burial of the vegetation. These are not satisfactory because there is no evidence that the vegetation in these areas was different and if it were it would require that practically all the coal in the bituminous area be derived from Equisetum or some such plant to give rise to so much ash. If the same plants underwent different degrees of decomposition, this would tend toward higher carbonization and therefore anthracitization but it certainly would not reduce the relative ash content in the anthracite. It would appear that the only explanation is found in the addition of more mineral matter to the vegetation while it was accumulating, or later by action of ground water percolating through the rocks.

It has been clearly shown that the anthracitization was not the result of igneous intrusions, nor does there seem in all parts of the field to be any relation between the lines of iso-anthracitization, and the original outline of the basin in which the coal was deposited, or the present outline of the basin. Strahan and Pollard have shown that there is with few excep-

[1] Strahan, A., and Pollard, W., Op. cit., p. 80.

tions a regular increase in anthracitization with depth and also in going westward from the eastern border of the basin, but they conclude that there is for them no satisfactory explanation for the origin of the anthracite. Differences in original vegetation are not satisfactory; nor is the metamorphism by pressure hypothesis substantiated as the iso-anthracitic lines do not correspond with the lines of disturbance, and the faulting which has so profoundly affected the region was later than the formation of the anthracite and has had little influence on it. Although the carbon-hydrogen ratio increases with depth there seems to be little or no difference between the coal in the anticlines and that in the synclines.

White considers that the *isovols*, or lines of equal volatile matter, in this field follow closely lines normal to the thrusts and that if the area were worked out on this basis the thrust-pressure hypothesis would explain the anthracitization. In the writer's opinion this is the only explanation, and the composite chart in Figure 33 indicates that the iso-anthracitic lines follow the outlines of the basin except for variations which would be the logical result of thrusting. An example of this may be seen on the chart in the Rhonda No. 2 vein.

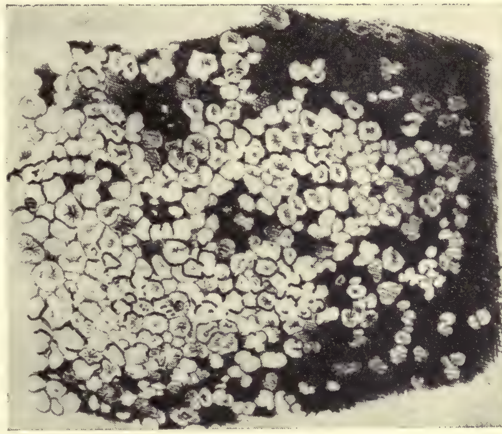
The best hypothesis so far offered for the origin of anthracite and the one which it is believed will explain its origin in all the fields so far studied, if logically applied, is the thrust-pressure hypothesis.

The Origin of Cannel and Boghead

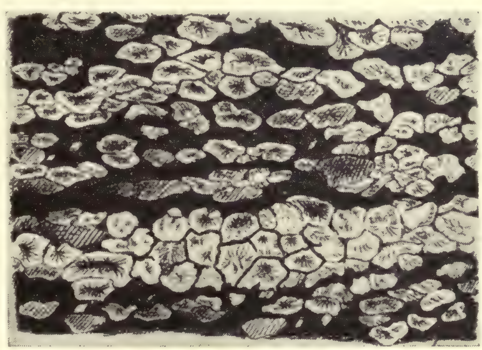
As early as 1833 Hutton[1] examined cannel coal under the microscope and found small "cells" which he said were of a resinous nature and contained a wine-yellow "liquid." This seems to have been the first time that the spores of cannel coal had been noticed. Balfour, Huxley, Dawson, Bertrand, Renault, and Jeffrey have since that time, in turn, studied these spores in detail and added much to our knowledge concerning them. There is now no doubt but that cannel consists almost entirely of spores and spore exines with some of the other more resistant portions of the vegetal matter. These bodies collect in open water and form layers usually of lens-shape, in the other types of coal.

[1] Hutton, W. Observations on coal. London and Edinburgh Phil. Mag. and Jour. of Sci., Vol. II, p. 302, 1833.

Cannel bears certain resemblances to the bogheads, including the varieties Torbanite, oil shales, kerosene shales, and bituminous schists. There seems to be little doubt that the organic matter of the latter rocks is a step nearer petroleum and natural gas than that of the ordinary coals and in this way petroleum is related to all coals through these types high in volatile constituents, especially the lighter hydrocarbons, and lower in the carbohydrates. The best known deposits of these rocks are the Torbanite of Scotland, the bituminous schists of Autun, France, and the kerosene shale of New South Wales, Australia.



(*a*)



(*b*)

FIG. 37. — (*a*) Horizontal section through the boghead of Autun showing Pila bibractensis (x 17), (*b*) Vertical section of same (x 38). (After C. E. Bertrand.)

Largely as a result of the work of C. E. Bertrand and B. Renault[1] it became generally accepted that these bogheads were formed from gelatinous algae. The rocks were studied microscopically and certain minute bodies were recognized as the thalli of algae (Fig. 37).

[1] Renault, B., and Bertrand, C. E., Note sur la formation schisteuse et le boghead d'Autun. Bull. Soc. l'industrie minérale, Tome 7, 3me Ser., p. 499, 1893. Also, Pila bibractensis et le boghead d'Autun. Soc. d'Histoire Naturelle d'Autun, Bull. 5, p. 159, 1892. Also, Reinchia Australis et Premières Remarques sur le Kérosène Shale de la Nouvelle-Galles du Sud. Soc. d'Histoire Naturelle d'Autun, Bull. 6, p. 321, 1893.

Bertrand[1] describes the algae as occurring as a hollow, compressed sack lying in a brown jelly, which is known as the fundamental jelly and which is said to carry many bacterial bodies. Between the thalli there are spores and grains of pollen forming thin laminae of orange or reddish-brown color. It is stated that the algae carry solid material to the extent of 0.015 to 0.030 of their volume.

Various names were applied to the supposed algae from different regions. Those from the boghead of Autun were known as Pila bibractensis and those from the kerosene shale of New South Wales as Reinschia australis. As Thiessen[2] has pointed out, however, there are many unsatisfactory features in Bertrand's explanation of the source of the bituminous matter which formed the fundamental jelly. Jeffrey[3] has attacked the works of Renault and Bertrand and has shown by means of modern section-making methods that these supposed algae are not thalli of algae but spores of vascular cryptogams. The openings in the supposed thalli are the tri-radiate lines on the spores. He explains the difference between cannel coals and boghead as due to the fact that the latter are composed of larger spores than the cannels, *i.e.*, they consist chiefly of macrospores. The fact that oil shales derive their oils and gases from spores has been verified by other investigators.

Jeffrey's conclusions have been generally accepted but one writer claims that he has obtained very strong evidence in support of the algal theory in some recent deposits in Russian lakes. M. D. Zalessky[4] states that he was inclined to agree with Jeffrey until he saw well preserved, silicified specimens of Pila from Autun and he has recently examined algal deposits which are now forming. In the brackish, shallow lake, Ala-Kool which lies at the southern extremity of the fresh-water lake known as Balkhash and which is overgrown with aquatic plants there lives the oleaginous alga, Botryococcus braunii

[1] Bertrand, C. E., Charbons gélosique et charbons humique. Compte Rendu VIII, Congrès Géologique International, p. 458, 1900.

[2] White, D., and Thiessen, R., The origin of coal. U. S. Bureau of Mines, Bull. 38, pp. 198–199, 1913.

[3] Jeffrey, E. C., The nature of some supposed algal coals. Proc. Amer. Acad. Arts and Sciences, Vol. XLVI, p. 273, 1910.

[4] Zalessky, M. D., On the nature of pila, the yellow bodies of boghead and on sapropel of the Ala-Kool Gulf of Lake Balkhash; Extrait du tome XXXIII des Bulletins du Comité Géologique, St. Petersburgh, No. 248, 1914.

in such superabundance that it would appear that sapropel might form from it on the lake bottom as in the case of the bogheads in Permian and Carboniferous time. The plankton algae come to the surface and they have been analysed by S. L. Ivanov, who obtained the following: Oil, 3.5 per cent; number of free fatty acids, 12; ether number 16; saponification number 28; iodine number 55.4. The sapropelic crust formed along the edge of the lake was also analyzed and with ether yielded 25 per cent of its substance. The ether was then evaporated and a hard, wax-like mass remained. This mass gave acid number 93.5 per cent; ether number 46.7; saponification number 140.2; iodine number 31.5; nitrogen, 0.4003 per cent. *Oleinic* acid was believed to be present.

A hydrogen sulphide fermentation takes place in the mass and when it is exposed to the air it changes from a green, movable body into a yellow-brown solid, elastic and reminding one of a mass of rubber, which can be cut with a knife. Thin sections show some preserved cellular structure of algae, the cavities of the swollen cells being represented by roundish pores. Zalessky claims that these are very similar to the structures seen in the silicified bogheads of Autun prepared as suggested by Jeffrey and he considers that Pila and Botryococcus are strikingly alike. The mud of Ala-Kool consists almost exclusively of algae of this type with a few other green algae and some diatoms.

The liquid product of B. brunni reminds one of tar with a slight benzine smell. There are solids like vaseline and other lubricants, and since Engler obtained artificial petroleum from oleaginous algae there would appear to be a possible source of petroleum in this type of plant.

These observations of Zalessky are very interesting as throwing new light on this subject, but it is doubtful whether he will convince most observers that algae were the source of the bogheads. It is peculiar that if these algae were so abundant during the formation of the coal measures they have not been more frequently recognized in coal deposits, while on the other hand it might naturally be expected that in the open waters of almost every swamp a considerable amount of such plant material should be laid down.

CHAPTER VII

FOSSIL FLORA OF THE COAL-FORMING PERIODS

Introduction

Plants are the source of all coal and therefore the types which formed it and their distribution are matters of vital interest to all who study the origin of coal deposits. The climatic conditions existing during the coal-forming periods and the question as to whether the plants of those periods were similar to those now living on the earth are also subjects for special consideration. The fossil plants are our best geologic thermometers and hygrometers and we are largely dependent upon them for our information regarding the earth's early climates.

In searching for plant fossils one seldom finds distinct forms in the higher grade coal itself unless they are enclosed in " coal balls " where they are almost hermetically sealed. The soft, semi-plastic vegetal matter which forms the coal is partially destroyed by bacterial action and oxidation and then is squeezed so that little sign of the original plants remains evident to the naked eye except that in some cases a large fragment of a tree trunk may resist complete destruction. In the coal balls the most delicate plant structures may be preserved and aside from them the best fossils occur in the shales and slates of the partings or in the roof or floor of the seam. Delicate structures are sometimes preserved in these rocks, which, being originally muds, have formed good coverings for the plants as they have sealed them very tightly. In the coarser sandstones and conglomerates only casts of the larger fragments of plants are preserved, due to two reasons, one the ready access of air and water to the plant fragment, causing it to decay without leaving a good imprint, and the other the coarseness of the material surrounding the plant. This prevents the various particles of the plant from being held in their proper position for the production of perfect impressions of its structure.

A study of fossil plants satisfies us that, in many respects, the

vegetation existing during the coal-forming periods was similar to that now found upon the globe. The changes from the earliest land vegetation to the modern types have, on the whole, been gradual although a few sudden and marked changes have occurred. The first great development of land plants, which made the formation of coal possible, occurred in the Devonian period, and from Upper Devonian time until the Pleistocene there was not a period in the earth's

Fig. 38. — Lepidodendron lycopodivides, (Sternberg) showing branches and leaves. (After Zeiller.)

history when coal was not fo ming somewhere on the earth. This indicates that the formation or non-formation of coal during any period since the first appearance of land plants has been fundamentally dependent upon the topographic and climatic conditions then existing on the globe rather than on the lack of plants or of any particular kind of plant. There seems always to have been a flora ready to

populate any region where conditions were suitable for development. Everything points to the fact that it matters little what kind of plant enters into the constitution of coal, but the physical and chemical changes which the vegetation later undergoes produce the profound differences in the different types of coal derived from it.

The Rise of the Land Plants

The two outstanding features in the evolution of the earth's vegetation are the great development of the Pteridophytes, known to many as the Vascular Cryptogams, in the early days of land plants, and the advent of the flowering plants comparatively late in the earth's history.

The Pteridophytes include the Filicales, or ferns; the Equisetales, or horsetails; the Lycopodiales, or lycopods, and the Sphenophyllales. All of these were present in the Devonian and they reached an extraordinary degree of perfection in the Carboniferous. The ferns have continued to flourish through all the periods to the present day, with the disappearance of many genera and the appearance of new ones. The horsetails had representatives in the Carboniferous which were good-sized trees, and they continued as such until the end of the Jurassic when the last great trees of this type disappeared and the group degenerated until it is now represented only by the insignificant Equisetum.

The lycopods of the genera, Lepidodendron and Sigillaria formed giant trees which were dominant in many of the coal basins. They disappeared very early in the history of land plants, Lepidodendron not even reaching the Permian and only a few species of Sigillaria existing in the lower portion of that system. For the sudden ending of these great genera in the Northern Hemisphere there is not much explanation because there seems to be little evidence of a sudden change in climate, although the prevalence of red beds and the presence of annual rings of growth in trees indicate approaching aridity and more distinctly marked seasons. In the Southern Hemisphere their extinction is more readily understood as it corresponds closely with the inception of glacial conditions which practically wiped out the previously existing flora and introduced the Gangamopteris flora containing, as common forms, Gangamopteris, Glossopteris and Rhacopteris. The latter flora has been an accompaniment of inter-

PLATE V.

A group of grains, cones, spores, and seeds from the Coal Measures of France. Figs. 1, 2, Male floral organs of cordaites; Fig. 3, Grains of pollen; Figs. 4, 5, 6, 7, Cordaianthus gemmifer; Figs. 8, 9, 10, 11, 12, 13, 14, 15, Cordaianthus baccifer; Figs. 16, 17, 18, Cordaicarpus major, ventricosus, vellavus; Figs. 19, 20, 21, C. Guthbieri, ovatus, congruens; Fig. 22, Cordaicarpus punctatus, Gr.; Figs. 23, 24, 25, C. drupacens, expansus, reniformis; Fig. 26, C. eximius; Fig. 27, Diplotesta Grand'Euryana (Brong.); Fig. 28, Carpolithes avellanus. (After Grand'Eury.)

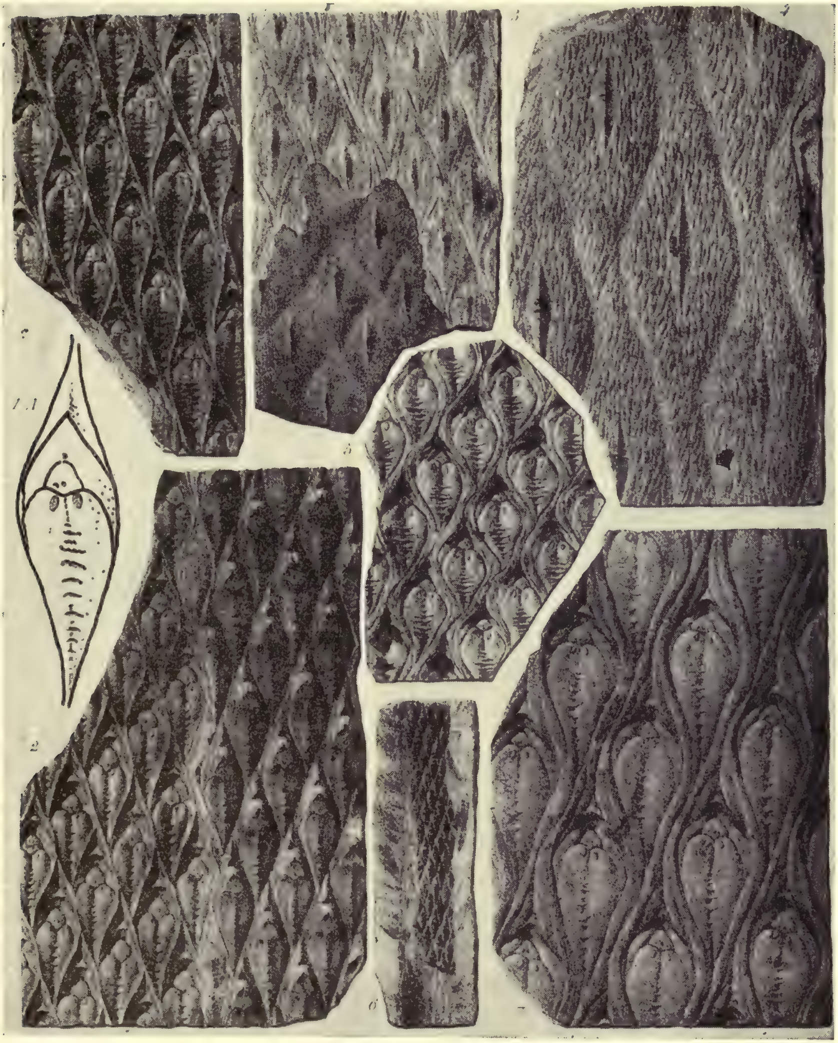
glacial periods in Australia, India, South Africa, and South America. All of these countries were more or less closely linked up in the Permo-Carboniferous by land connections. This flora has also been found to a limited extent in the Northern Hemisphere as, for example, in European Russia which could be easily reached from India since the Himalaya Mountains were not then in existence.

This change in the vegetation of the Southern and to a lesser extent in that of the Northern Hemisphere is the most sudden change in the history of plant life on the earth. In the coal fields of America there was a great change in the vegetation during the Permian, as every species, but not every genus, of the Coal Measure plants disappeared early in that period. The increasing dryness and the elevation of the Appalachian Mountain system had a profound influence on the flora of the eastern part of the continent, which was the only great land area at that time as most of the western portion of the continent was under the sea. Many genera and some families ceased to exist, and when the Triassic period opened the Gymnosperms had become the dominant type of vegetation in place of the Pteridophytes, or Vascular Cryptogams.

The Gymnosperms, or "naked-seed" plants were represented in the Devonian by the Cycadofilicales, a group of seed plants which strongly resembled some of the ferns in appearance but which bore seeds and were similar to the cycads in some other respects. These plants occupied a very prominent position in the Carboniferous period and were for a long time mistaken for ferns. The Gymnosperms were also represented by the conifers which appeared in the Devonian and which left some traces in the Carboniferous. In the Permian, Walchia and Voltzia were typical examples of this group, which became much more prominent in the Triassic than it had been previously. During the Jurassic some of our more modern types of conifers, like the pine and the cypress, appeared and continued to flourish.

Another great Gymnosperm group was the Cordaitales which appeared in the latter part of the Devonian period, became very abundant in the Carboniferous and gradually died out before the close of the Paleozoic. These plants were probably the ancestors of the Gingkoales. The latter became abundant in the middle of the Mesozoic era and then gradually declined until the group is now represented by the single species, Gingko biloba. The cycads were

PLATE VI.



Lepidodendron aculeatum (Sternberg) showing the leaf scars and the varying appearance of these when portions of the bark are removed. *1 A* is an enlargement of one of the leaf cushions, and *7* illustrates the bark of an old tree. (After Zeiller.)

represented in the Coal Measures and they gradually developed to a climax in the Jurassic. They have since declined in relative importance.

From the Triassic, which seems to have marked the beginning of the dominance of the more modern vegetation over that of the Paleozoic, the flora has become more and more like that with which we are now familiar. There were periods of adversity for the plants and there were periods like the Jurassic and early Tertiary when the climate seems to have been fairly uniform from the equator to the poles. During these periods the tropical and subtropical species spread far to the north and south as they did in the Carboniferous, and the remains of plants like the cycads, which we now think of as tropical and subtropical lie beneath the Arctic snows.

In the Triassic[1] the Gymnosperms were dominant but the flora on the whole was not luxuriant as in the Carboniferous. The horsetails were large and abundant. There were many ferns and conifers. The cycads were beginning to be numerous.

The Jurassic period showed a much greater development of modern genera than did any previous period. The cycads reached their climax and the period has been called the "Age of Cycads." Modern conifers like pines, arbor vitae, and cypresses appeared.

With the opening of the Lower Cretaceous, or the Comanchean of America, an important event in the evo ution of plants occurred. This was the appearance of the Angiosperms, or "enclosed-seed" plants. These flowering plants, apparently originating in the northeastern part of the continent, soon spread all over it, and many modern genera of eucalypti, figs, magnolias, cinnamon, and others well known today, made their appearance and have contrived to flourish to the present time. In the Upper Cretaceous the beech, birch, oak, walnut, breadfruit, and holly were all present and the flora had assumed quite a modern aspect.

Classification of Plan

In a classification of plants which includes foss'l types it should be pointed out that the fossil plants must be divided into genera which are founded on a basis different from that used in a classification of

[1] Fontaine, W. M., Older Mesozoic flora of Virginia. U. S. Geol. Survey, Monograph VI, 1883.

living plants. This is owing to the incompleteness of the fossils since parts of the plant may be separated from each other or entirely destroyed. It is necessary to classify them into what may be called " form " genera, based on the form of the fragment. For example, the genus Lepidodendron includes the stem of a tree and Stigmaria the root of the same tree. Such an arrangement of genera is not found in the classification of living plants.

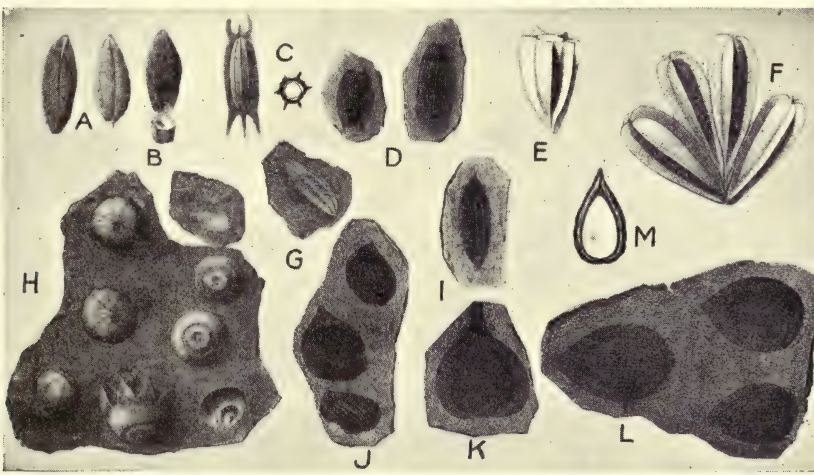


FIG. 39. — Group of grains representing the seeds of various plants in the Coal Measures of France A, B, Trigonocarpus (Brong.); C, Polylophospermum (Brong.); D, E, F, Polypterocarpus; G, H, Codonospermum (Brong.); I, Carpolithes sulcatus (Prest.); J, K, L, M, Rhabdocarpus (Gopp and Berg). (After F. C. Grand'Eury, Floré Carbonifére du Département de la Loire.)

Many botanists have divided all plants into two large groups, the Cryptogams or spore-bearing plants, and the Phanerogams, or flowering plants. The former supposedly included all those in which the sexual reproduction is concealed, thus embracing all the lower types. In the Phanerogams the reproduction was thought to be exposed in the stamens and pistils which were mistaken for sexual organs. In this division were placed all the seed plants.

In more recent classifications, however, the seed plants are known as *Spermatophytes* and they are divided into the *Gymnosperms* and *Angiosperms*, the former comprising the primitive seed types and the latter the more highly developed and more modern flowering plants. As might be expected, the older fossil seed plants all belong

to the Gymnosperm group as do also many of the later fossils, and our discussion of the coal flora will be confined largely to a discussion of this group, as the Angiosperms did not appear on the earth, so far as known, before the Cretaceous period. In a modern classification[1] of plants the following divisions are recognized: (1) *Thallophytes*, (2) *Bryophytes*, (3) *Pteridophytes*, and (4) *Spermatophytes*.

(1) The Thallophytes

The *Thallophytes* are plants of the simplest form and they get their name from the fact that with few exceptions they consist only of thalli. The thallus is an undifferentiated vegetal body which in its lowest form, like the animal amoeba, does not have a division of functions. In such forms the jelly-like mass of protoplasm can push out legs, or pseudopodia for purposes of locomotion and these may surround particles of food which become engulfed in the mass and are absorbed. The processes of reproduction are simple. In some cases there is simple division, in others a spore is produced which gives rise to the new plant. Some of the higher forms possess multicellular sex organs.

There are two important divisions of the Thallophytes including (1) Algae and (2) Fungi. The Algae are subdivided according to color into the "Blue-Green," the "Green," the "Brown" and the "Red" Algae.

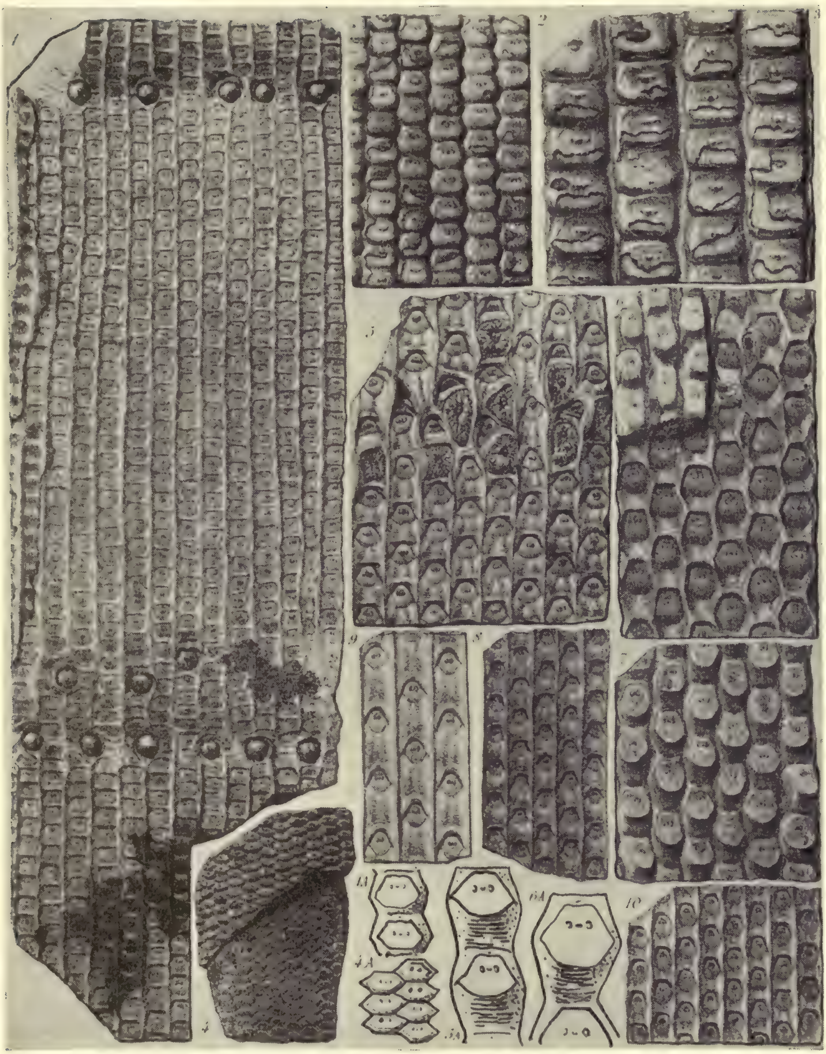
The Fungi are subdivided into at least four groups which contain respectively, the water moulds and the mildews; rusts and smuts; the toadstools, mushrooms and puffballs; the bacteria and the lichens.

The Algae vary in size from microscopic organisms to the large seaweeds, and many of the Fungi are so minute that they cannot be seen with the naked eye.

From a palaeontological standpoint the Algae existed in pre-Cambrian time and they have been abundant in certain geological periods, although it is doubted whether they played any important part in the formation of coal. Bacteria have also been in existence since early geological time and their influence in coal formation has been discussed in connection with the biochemical processes in the origin of coal. It is believed that fungi such as mushrooms have also

[1] Coulter. J. M., Barnes, C. R., and Cowles, H. C. A textbook of botany, Vol. I, 1910

PLATE VII.



1—4, Sigillaria elegans (Sternberg); *5—10*, Sigillaria mamillaris (Brongniart). These figures illustrate the different appearance of the specimens when portions of the bark have been removed. *1* and *5* show the scars of the organs of fructification as well as the leaf scars; *4* and *6* show the posterior side of the bark; *10* is from a young tree. (After Zeiller.)

been instrumental in producing biochemical changes in peat as far back as the Carboniferous period. Any evidence of fossil Thallophytes, so far as known, can be seen only by aid of the microscope and therefore these plants do not concern the average person collecting plant fossils.

(2) The Bryophytes

The *Bryophytes* are a large group of plants showing a distinct advance over the Thallophytes in structure. They show a definite *alternation of generations* and are characterized by sexual and sexless individuals. The *gametophyte* produces the sex organs and the *sporophyte* produces the spores. The members of the group possess an *archegonium* which is characteristic of higher plants, and they thus show their relation to these higher forms. They possess a multicellular *antheridium* much more highly developed than that of the Thallophytes.

This group is divided into two main divisions (1) *Hepaticae* or liverworts and (2) *Musci*, or mosses, including the Sphagnales or " bog mosses "; the Andreaeales; and the Bryales, or " true mosses." The Bryophytes, or Bryinae are regarded by Land and others as of recent origin although it has been claimed that barren forms of this group have been found in the Carboniferous of France. They are of little interest from the palaeontological standpoint but the Sphagnales, comprising the genus Sphagnum, are of much interest at the present time because of the importance of this genus in the formation of peat in the cooler climates.

(3) The Pteridophytes

The group of *Pteridophytes* contains many important fossil species in addition to numerous well-known living forms, such as ferns, horsetails and club-mosses. They are characterized by a vascular system, or series of vessels for conducting material from one part of the plant to another, and from this character they are frequently known as the Vascular Cryptogams. This vascular system serves to separate the Pteridophytes very sharply from the Bryophytes and Thallophytes, but it is found in the Spermatophytes and shows the relation of the Pteridophytes to these higher seed plants. The *gametophyte*, known as the *prothallium*, and the *sporophyte* are independent of each other.

The prothallium develops from a spore and on it the *oospore* develops in the *archegonium*, giving rise to the *sporophyte*, the full-fledged

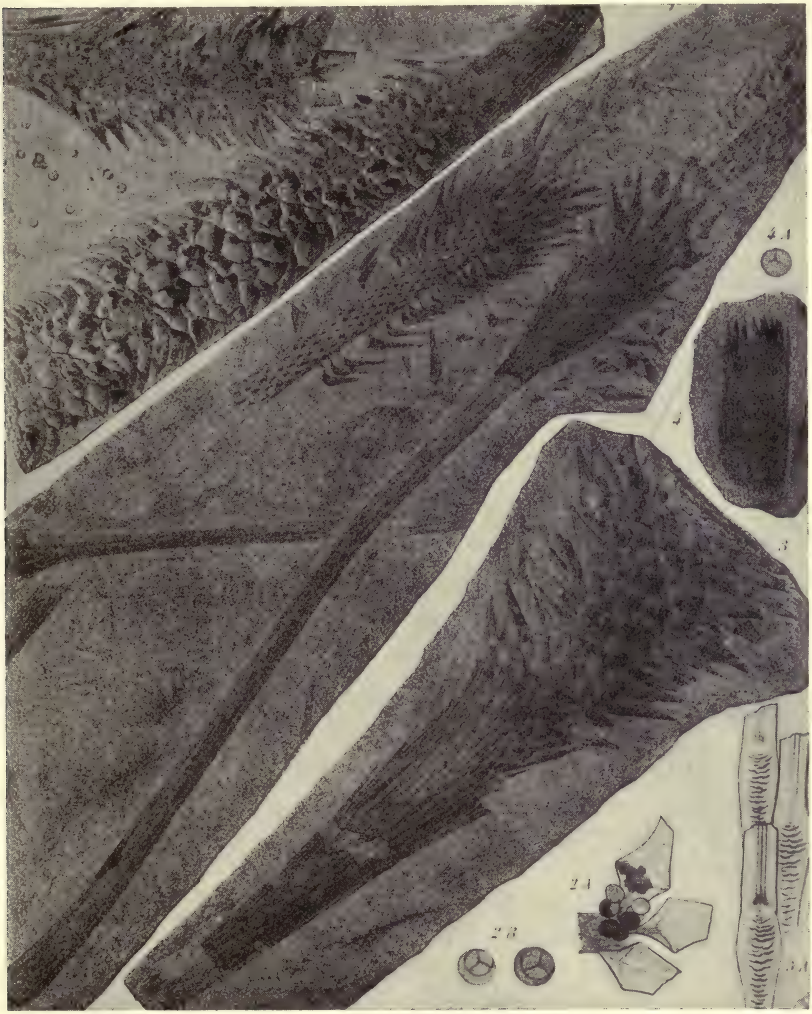


FIG. 40. — *1* Sigillariostrobus goldenbergi. (O. Feistmantel.); *2* S. tieghemi (Zeiller); *4* S. goldenbergi (Zeiller); *1*, *2*, *2 A* and *4* show cones of fructification; *2 B* and *4 A* are macrospores enlarged. (After Zeiller.)

plant, bearing spores in the *sporangia*. Most people are familiar with the dark spots on the under side of fern leaves. Each of these spots is a group of sporangia known as a *sorus*. It is considered that

the Pteridophytes have been developed from a liverwort-like ancestor.

This group has been subdivided by Coulter, Barnes, and Cowles[1] into six groups as follows: (1) *Lycopodiales* or club-mosses, (2) *Psilotales*, (3) *Sphenophyllales*, including only the fossil genus *Sphenophyllum*, (4) *Equisetales*, or "horsetails," (5) *Ophioglossales*, including the common adder's tongue and moonwort, and (6) *Filicales*, or ferns, including the Filicineae or "true ferns" (*homosporous*) and Hydroteridineae, or "water ferns" (*heterosporous*).

Zeiller[2] makes the following four divisions (1) *Filicineae*, or ferns, (2) *Rhizocarpeae*, or *Hydropterides*, often placed as a sub-class under the Filicineae, (3) *Equisetineae* and (4) *Lycopodineae*. Of these (1), (3) and (4) are well represented among the Coal Measure fossils, but (2) is absent unless Sphenophyllam be put in that class as some have placed it, although it is more nearly related to the Lycopodineae. It has no living representative.

(1) The Lycopodiales. — There are several living and many extinct genera in this group. **Lycopodium,** which is the best known, has been characterized by Coulter as possibly the best living representative of the earliest forms of vascular plants. Some have regarded Phylloglossum, an Australian species, as the most primitive Pteridophyte.

In Lycopodium the plant, or *sporophyte*, is a branching stem covered with many small leaves and on each of these there is a *sporangium* on the upper side. The term *sporophyll* is applied to these spore-bearing leaves and when grouped together they form a *strobilus*. There is a tendency in some of these plants for the lower leaves to become sterile and cease to bear *sporangia*, while this function is carried on entirely by stalk-like sporophylls rising above the foliage leaves.

The stem shows two zones, an outer one of cells known as the *cortex* and an inner one known as the *stele* in which the vascular system is found. From the vascular cylinder, strands extend through the cortex to form the leaf traces on the exterior.

The Lycopodiales, although now represented only by the humble club-mosses, were in Carboniferous time among the large trees and their fossil forms are as a rule arborescent.

[1] Op. cit., p. 122.

[2] Zeiller, R., Bassin houiller de Valenciennes, Description de la Flore Fossile, Text and Atlas. Paris, 1888.

Two well-known families, Lepidodendrae and Sigillariae, are found widely distributed in later Paleozoic rocks. Under the Lepidodendrae several genera have been recognized: Lepidodendron (Sternberg), Lepidopholios (Sternberg), Halonia (Lindley and Hutton), Bothrodendron (Lindley and Hutton), Lepidostrobus (Brongniart), Lyco-

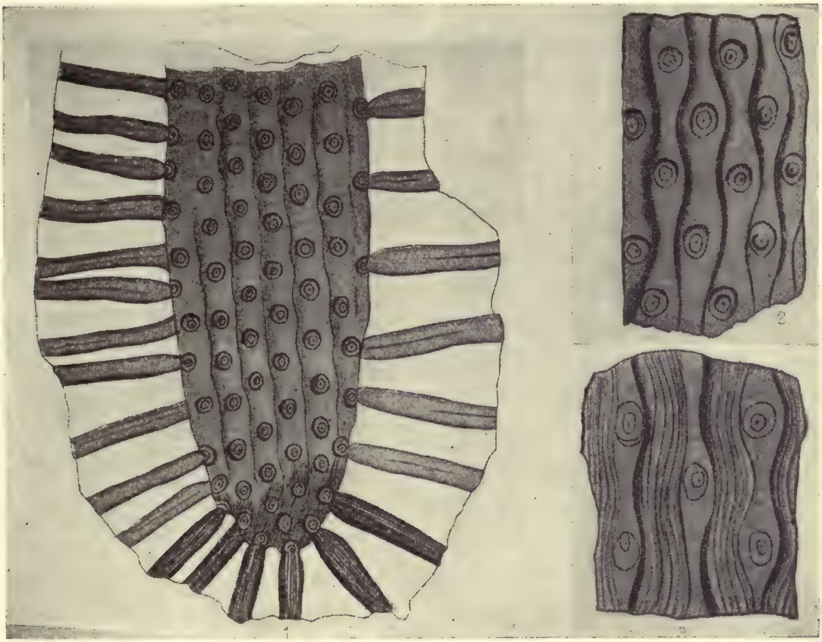


FIG. 41. — *1* Stigmaria ficoides (Brongniart) showing main roots and attached rootlets; *2* and *3*, Scars where rootlets have been attached. (After Lesquereaux, Pa. Geol. Survey.)

podites (Brong.), Lepidophyllum (Brong.). Of these Lepidodendron is best known and it will be described as a type.

Lepidodendron (Sternberg): Plants of this genus formed trees in Paleozoic time which according to Grand'Eury[1] reached a meter in diameter and 30 meters in height, with leaves in some cases a meter long. They and the Sigillariae are so abundant in the Coal Measures and their stems are so characteristic that they have always attracted a great deal of attention among miners and others collecting plant fossils. *Sigillaria* is recognized by the parallel vertical lines of leaf

[1] Grand'Eury, F. C., Flora carbonifère du Departement de la Loire et du Centre de la France; Paris, p. 148. 1877.

cushions on the bark while *Lepidodendron* is distinguished from it by its spirally arranged lines of leaf scars.

The leaves of Lepidodendron are generally acicular, and very long on the stems, but much shorter on the branches; they diminish in size with each bifurcation of the axis. On the stem they are attached to elongated-rhomboidal to pointed-oval cushions, (Fig. 38). When the epidermis is present these cushions show three bodies making up one structure roughly oval in outline and sharply tapering at one end. The other end is capped by a small rhomb with three small dots. Above this rhomb, close to the end of the cushion, is a small scar representing the leaf-detachment scar. The small dots are regarded by most writers as leaf-bundle traces, although some think that only the middle one is of this origin. If the outer bark be removed, a new condition is presented and each cushion shows only one scar at the top. (Plate VI.)

The cushions are in contact with one another except that in some specimens they are separated by sharp furrows and in others by broad flat strips. According to Stur[1] who has given detailed descriptions of these fossils, the former are older plants than the latter.

As to the reproduction of the arborescent fossil Lycopods, Zeiller[2] says that they appear to have been heterosporous. The greater part of the cones of fructification in which the structure has been studied seem to carry the macrosporangia on the lower and the microsporangia on the upper bracts. He still feels, however, that the matter has not been fully settled.

Geologic and geographic distribution: Lepidodendron was widely distributed over the earth in Carboniferous and sub-Carboniferous time. It seems to have been found in every country where coal was forming at that time, reaching its maximum development in the lower and middle Coal Measures and then declining. In Australia no trace of it is found even in the Permo-Carboniferous deposits as it had died out before they were laid down, and in Europe it barely extends into the Permian. In North America it has not extended

[1] Stur, D., Die Culmflora der Ostrauer und Waldenburger Schichten. Abh. d. k. k. Geol. Reichsanstalt zu Wien, Vol. 8, Heft II, also Die Culmflora des mahrisch-schlesischen Dachschiefers, Heft I, 1877. Quoted by Solms-Laubach in Fossil Botany, Rev. Trans. by Balfour, I. B., 1891.

[2] Zeiller, R., Op. cit.

into the Permian.[1] It is confined, therefore, to the Paleozoic. The earliest appearance of the genus is reported to be in the Lower Devonian beds of Wieda and Hartz.[2] It is widely distributed in America,

FIG. 42. — *1–2 aa*, Annularia longifolia (Brongniart); *2 b, 2 bb*, A. inflata (Lesquereaux); *3, 3a*, Asterophyllites equisetiformis (Brong.); *4–5a*, A. gracilis (Lesq.); *6, 7*, Sphenophyllum schlotherinne (Brong.); *8, 9*, Annularia sphenophylloides (Zenk.); *10, 10a*, Sphenophyllum bifurcatum. (After Lesquereaux, Pa. Geol. Survey).

Europe, and Australia in the Upper Devonian and the Mississippian, or Sub-Carboniferous.

Sigillariaea: Under the family *Sigillariaea* have been described the genera Sigillaria (Brongniart)[3], Sigillariostrobus (Schimper), and Stigmaria (Brong.). It has been known, however, since the work of Binney that Stigmaria is not a genus but simply the root of Sigillaria and Lepidodendron.

[1] Solms-Laubach, Fossil botany. Rev. Trans. by Balfour, I. B., p. 194, 1891.

[2] Fontaine, W. M., and White, I. C., Permian flora. 2nd Geol. Survey Pa., Pt. PP, p. 114, 1880.

[3] Solms-Laubach, Op. cit

Of the others, *Sigillaria* (Brong.)[1] is by far the best-known genus. As already stated, it may be distinguished from Lepidodendron by the fact that the *leaf scars* are arranged in vertical, parallel bands rather than in spirals. Our knowledge of the leaves and many other features is not as great as it is of those of Lepidodendron.

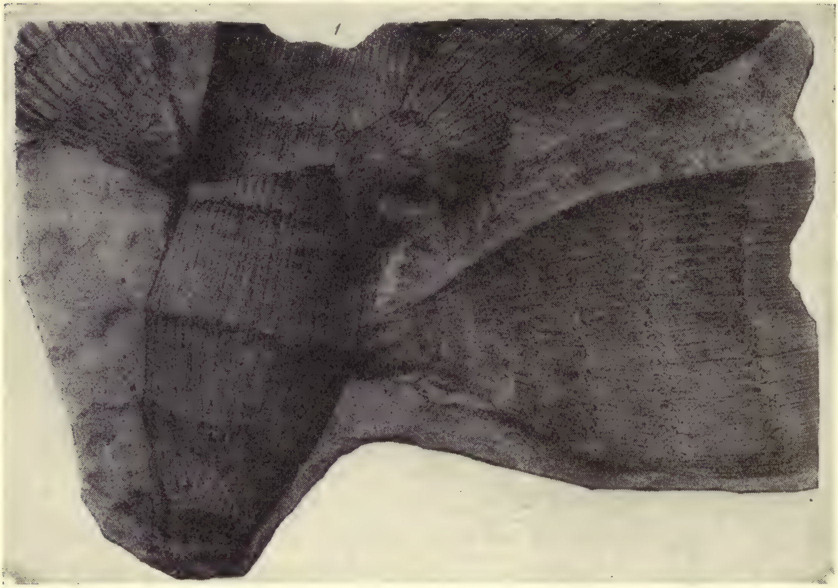


FIG. 43. — Calamites suckowi (Brongniart) with articulations and secondary branches. Coal Measures of France. (After Zeiller.)

The leaf cushions are roughly polygonal in outline and they may be compressed vertically so as to give a transversely elongated six-sided figure with the two horizontal sides considerably longer than the other four, which are approximately equal. (Plate VII.) When of this form they are compressed together so that they form vertical ribs of scars alternating in adjacent rows.

Along the upper side of the cushion there are three small marks. The middle is punctiform or somewhat elongated transversely, while the others are short, thin marks diverging from it. These marks represent the *leaf traces*.

[1] Brongniart, A., Observations sur la structure intérieure du Sigillaria elegans comparée à celle des Lépidodendron et des Stigmaria et à celle des végetaux vivants. Archives du Muséum d'Hist. Nat. Vol. I, 1839.

There is a good deal of uncertainty about the leaves of Sigillaria, but leaves which are believed to be from these trees have been described by a number of botanists. They are long and have a keel resulting from the projection of the median nerve. White[1] has found leaves in the Missouri Coal Measures which he describes as probably belonging to Sigillaria. They were broad, rather thin, but seldom flattened. Some fragments were 20 cm. long and 5 to 11 cm. in width. They tapered very gradually and, from the appearance of certain fragments, the entire leaf must have been 40 to 50 cm. in length before being broken. The upper surface showed a strongly marked furrow 2 to $2\frac{1}{2}$ mm. in width. The lower surface of the leaf was marked by a carene about 2 mm. wide and on either side of this there was a well-defined crease, probably the stomatiferous crease previously described by Renault.

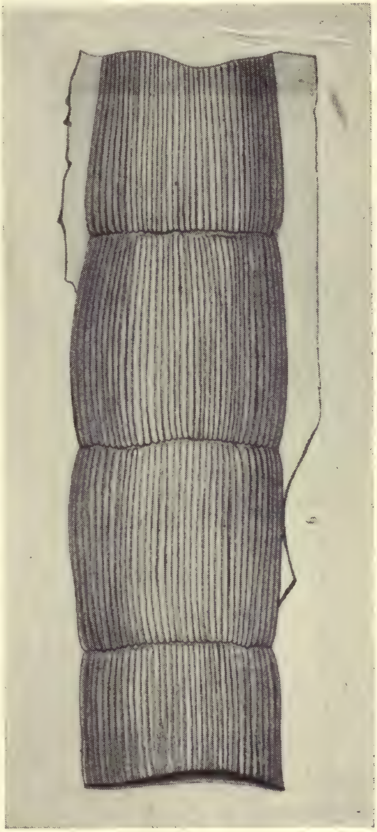


FIG. 44. — Calamites cistii (Brongniart). (After Lesquereaux Pa. Geol. Survey.)

Dichotomous branching has been found in this genus but stems are frequently single.

In the matter of reproductive organs it has been observed that the regular bands of leaf scars are frequently curved or irregular and that lying between them there are other scars which are rounded or angular and which differ considerably from the leaf scars. These are supposed to be the scars left by the organs of fructification. Much interest has been attached to Zeiller's[2] discovery of Sigillarian cones

[1] White, D., Flora of the outlying carboniferous basins of Southwestern Missouri. U. S. Geol. Survey, Bull. 98, p. 103, 1893.

[2] Zeiller, R., Cones de fructification des Sigillaires. Ann. des Sci. Nat., Sér. 6, Tome 19, 1884.

on long stalks with the leaves bearing sporangia standing out from the stem. Since he could only find macrospores he considers either that these trees were homosporous, or that the two types of spores were produced on different cones and the macrospore cones were not found. The discovery of these cones has led some botanists, such as Renault, to regard some of the Sigillariae as closely related to the cycads, but such relation has not been substantiated.

Geologic and geographic distribution: Sigillaria did not make its appearance in Europe before the beginning of the Carboniferous, and very few specimens are found in the Millstone Grit. It seems to have reached a climax about the middle of the Coal Measures and then declined. The Rothliegende is probably the latest formation in which remains are found. This family is not mentioned as occurring in Australia or New Zealand and it seems to be considerably more restricted geologically and geographically than Lepidodendron. In North America only two species reach the Permian and they disappear early in that period.

Stigmaria ficoides (Brongniart):[1] The fossils known as Stigmaria were in early days thought to be a genus of plants. They are extremely abundant in the " seatearth " under the coal seams of many fields, and the finding in England of these bodies actually attached to stumps of Sigillaria and Lepidodendron has settled their derivation. They are probably the roots of a few other genera also and it is interesting to see how similar are the roots of so many of these trees. The scars on the roots are the markings of the rhizomes or rootlets, and specimens have been found with dichotomous branches (Fig. 41). Very often these roots when broken open exhibit a cylindrical body which readily separates from the exterior coating and which seems to be a cast of the central cylinder.

(2) **Sphenophyllales.** — The Sphenophyllales are not represented by a living species. The only genus is Sphenophyllum (Brongniart)[2] which is well represented by fossils in the Coal Measures. There has been much difference of opinion regarding its relations. Some

[1] Renault, B., et Grand'Eury, Étude sur les Stigmaria, rhizomes et racines de Sigillaries. Annales des Sciences géologiques, Tome 12, 1881.

[2] White, D., Op. cit., p. 35; Coemans, E. et Kick, J. J., Monographie des Sphenophyllum d'Europe, Bull. de l'Acad. Roy. d. Belgique, 2me Sér., Tome 18, p. 134, 1864; also Newberry, J. S., The Genus Sphenophyllum. Jour. Cincinnati Soc. Nat. Inst. XIII, p. 212, 1891.

botanists consider it as most closely related to the Lycopodiaceae while others regard it as being more nearly related to Calamariae. Members of this genus are herbaceous, the stems are simple or branched, and the surface is canaled. The leaves are in verticils on the strongly marked articulations and in groups of three. The leaves are sessile as a rule but they may occur on pedicles. Those on the stipe are different from those on the habetas.

FIG. 45. — *1*, *1a* Sphenopteris subalata (Gein); *2*, *2b*, S. brittsii sp. nov.; *3–4a*, S. goniopteroides sp. nov.; *5*, *5a*, S. hoeninghausi (Brongniart); *6*, *6a*, S. elegans (Brong.); *7*, *7a*, S. larischi (Stur); *8–9a*, S. tridactylites (Brong.). (After Lesquereaux, Pa. Geol. Survey.)

The center of the stem consists of a triangular axis made up of three vascular bundles. Exterior to these is a ring of large aqueous tubes with lateral tangential growth.

The bark is thin, lacuneous and generally poorly preserved. The branches are single on articulations. The roots are cylindrical and the arrangement of the wood in them is much like that of the stem.

The sporangia are borne on the bracts at some distance from the

axis and are marked at the point of attachment by a small circular umbilical depression.[1]

Geologic and geographic distribution: In Europe Sphenophyllum extends from the Culm to the lower Rothliegende and was a very prominent genus in the middle and upper Coal Measures.[2] It is not mentioned as occurring in Australia. In North America this genus occurs from the lower Coal Measures to the Permian.

(3) **Equisetales.** — The *Equisetales*, or horsetails, include the order *Equisetineae*, which in turn includes the family *Calamarieae*. This group, which formed a great arborescent flora in the Paleozoic, is now represented by the single genus *Equisetum*, a genus of small, insignificant plants preserving many of the characteristics of the fossil trees and commonly known as *scouring rushes*.

Of the Calamarieae Renault states that these include all fossil plants, either Cryptogams or Phanerogams, which present a calamitoid stem, i.e., a stem of which the central part is occupied by a relatively voluminous pith, its length being divided into a series of similar articulations which may or may not be related to the articulations of the sheath.[3] He would then divide the Calamarieae into two divisions, the *Equisetinées* and the *Calamodendrées*. The first would include the articulated plants containing only primary wood, some of which reproduce by simple spores, i.e., are *isosporous*, like the modern Equisetum, while others carry both microspores and macrospores. As examples the genera *Annularia* and *Asterophyllites* are cited, (Fig. 42). *Calamites* apparently belongs here also. The second division includes those which have the secondary wood more or less well developed and which in their organs of fructification more nearly approach the phanerogamic plants than do those of the other division. Of the family Calamarieae, *Calamites* (Suckow) (Fig. 43), and *Annularia* (Sternberg) are the best known genera. Other genera are *Pinnularia*, *Asterophyllites*, and *Calamophyllites*.

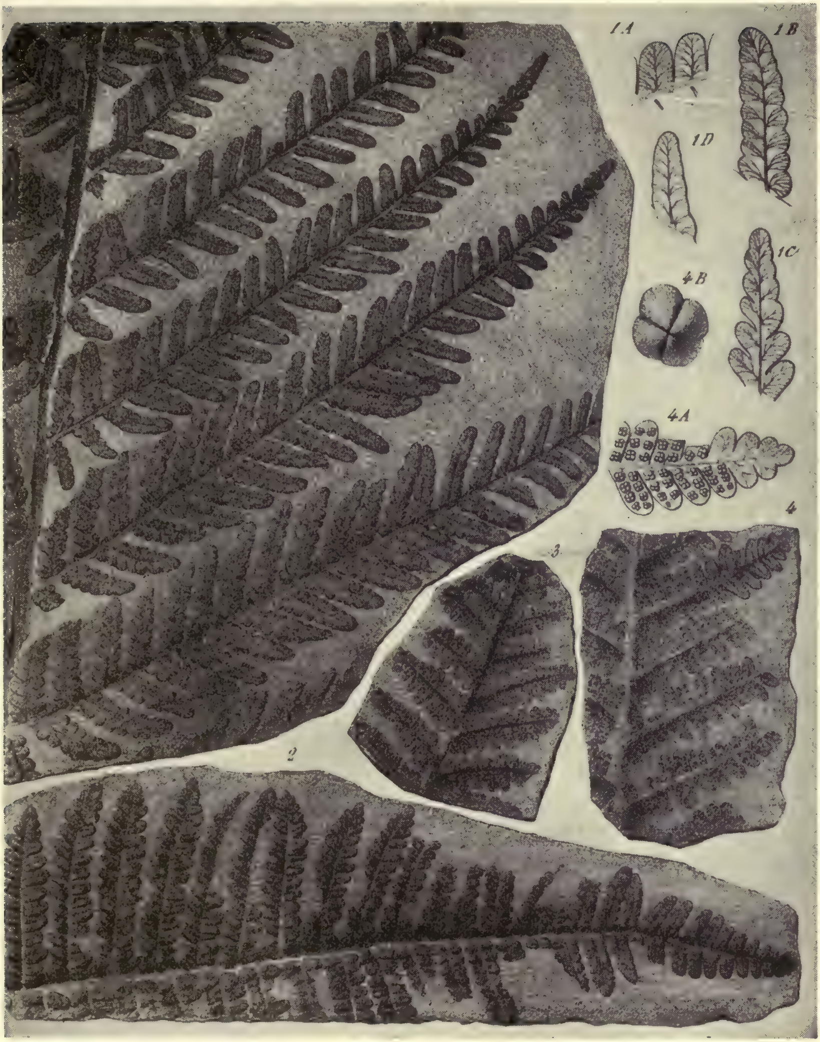
In these plants the surface of the stems, the roots and their branches are marked by ribs and longitudinal furrows. The bark appears smooth but little furrows may be found. In some species the furrows

[1] Renault, B., Bassin houiller et Permian d'Autun et d'Epinac. Flore Fossile, Text and Atlas, Fasc. IV.

[2] Solms-Laubach. Op. cit., p. 343.

[3] Renault, B., Op. cit., p. 60.

PLATE VIII.



Pecopteris (Asterotheca) abbreviata (Brongniart.) *1*, Illustrating the gradual dividing of the pinnules near the inner end of the frond; *3, 4* Fertile pinnules; *4 B* Spores enlarged 40 times. Coal Measures of northern France. (After Zeiller.)

alternate at the joints and in some they do not. The roots have an organization similar to that of the stem and frequently the aërial stems rise from articulations of the roots. The racines and leaves are arranged in verticils at each node on the root, stem, or branch. The leaves are simple and uninerved, sometimes free and sometimes in a collarette along the stem and branches. *Sporangiae*, attached to the borders of transformed leaves, are generally disposed in numerous verticils connected and forming the cone.

FIG. 46. — *1* Odontopteris alata (Lesquereaux); *2* O. brardii? (Brongniart); *3, 4* O. sphenopteroides sp. nov.; *5, 6* O. subcrenulata sp. nov.; *7, 7a* O. abbreviata sp. nov.; *8* O. aequalis (Lesq.) (After Lesquereaux, Pa. Geol. Survey.)

These plants are believed to be *isosporous* like the modern representatives of this group.

Geologic and geographic distribution: Calamites and Annularia seem to have made their appearance with the Carboniferous rocks, although members of the Equisetales were present in the Devonian formation and extended through that system and into the Permian. They were extremely important in the Carboniferous and representa-

tives of the Equisetales have continued to flourish through the geological periods to the present day. They continued to form large trees until the end of the Jurassic period, but in the Cretaceous they degenerated into small plants. As well as having extensive geological distribution these plants were widely distributed in Australia, Asia, Europe, and America

FIG. 47. — Neuropteris heterophylla (Brongniart) showing the development of primary and secondary pinnules. Coal Measures of France. (After Zeiller.)

(4) Filicales, or Ferns. — As previously intimated, the *Filicales* are divided into two groups, the *Filicineae* or " true ferns " which are *homosporous*, and the *Hydropteridineae* or " water ferns," which are *heterosporous*. The true ferns include such types as the royal ferns, tree ferns, filmy ferns and ringless ferns. The members of the group extend from the Devonian period to the present and some of them were very prominent in the coal measures of various periods.

They may be arborescent or herbaceous, the height of some of the arborescent varieties being as much as 20 meters.

The classification of the living ferns is based chiefly on the nature of the sporangia. Zeiller[1] states that on this basis ferns may be divided into two large groups, *Leptosporangiae* or the ferns proper, and *Eusporangiae* or *Marattiadiae*. In the former group each sporangium springs from only one epidermic cell and when it is ripe the

FIG. 48. — *1, 4, 5, 7, 9, 12* Neuropteris hirsuta (Lesquereaux); *2, 3, 6, 8, 10, 11*, N. angustifolia (Brongniart). (After Lesquereaux Pa. Geol. Survey.)

walls are formed of only one layer of cells. In the latter sub-class each sporangium proceeds from a subepidermal cell, and when mature the walls are relatively thick since they are constituted of several layers of cells.

In the case of fossil ferns it is generally necessary to follow Brongniart's system[2] and classify them according to the nature of the fronds

[1] Zeiller, R., Bassin houiller et Permien d'Autun et d'Epinac. Études des gîtes minéraux de la France. Fasc. II, Pt. I, Flore Fossile, (Fougères) 1890.

[2] Brongniart, A., Histoire des végétaux fossiles, 1828.

and the nervation since the organs of fructification are infrequently preserved. One of the striking features of all ferns is the highly divided character of the leaves. The method of division has been used as a means of classification by Brongniart and others, but that system is not very satisfactory. The organs of fructification, or sporangia, where preserved, are found on the under side of leaves and form little globular sacs containing a considerable number of spores which are set free by rupture of the wall of the sporangium. The spores give rise to the *prothallium*, a vegetative apparatus which carries both the male and female organs.

On the basis of the manner of attachment of the pinnules and the nervation the ferns may be divided into the following six groups:[1]

1. Sphenopteridae, in which the frond is finely divided and the pinnules are small;
2. Pecopteridae with pinnules attached to the rachis for all their width;
3. Odontopteridae with pinnules equally fixed to the rachis for all their width but without the distinct median nerve;
4. Neuropteridae with pinnules generally quite large, rounded, and often notched in the center of their base, attached at only one point;
5. Teniopteridae with simple fronds, ribboned, much longer than wide, the edges entire or feebly crenulated;
6. Dictyopteridae, including all forms in which the nervation anastomoses and forms a more or less complex network instead of remaining separate.

In cases where the organs of fructification have been found, a more logical and genetic arrangement may be made, but the classification has never been satisfactory.

Following unsatisfactory attempts to classify the ferns thus, recent work by Grand'Eury, White, Kidston, Oliver and Scott has shown that many of these plants are not ferns and that they should be placed with the Gymnosperms as the most primitive of these plants. For those plants which bear seeds and which had formerly been called Cycadofilices because they combined in the stem the

[1] Zeiller, R., Op. cit.

characters of ferns and cycads, Oliver and Scott[1] have proposed the name *Pteridospermae.* In this group Zeiller[2] considers that there should be placed several of the Sphenopteridae, some Pecopteridae such as Pecopteris fluckeneti and Pecopteris sterzeli, probably all the Alethopteridae comprising probably Callipteridium and Callipteris, also all the Odontopteridae and Neuropteridae. He considers that it would be easy to change the two last-named families but there is much uncertainty about many of the others such as the Alethopteridae,

FIG. 49. — Taeniopteris Newberriana sp. nov. From the Permian. (After Fontaine and White, Pa. Geol. Survey.)

and that three groups might be made, including the Filicineae, the uncertain forms and the Pteridosperms. In this division Zeiller would leave with the ferns those plants whose fronds carried the filicoid fructifications but whose male apparatus is like that of the Pteridosperms.

Geologic and geographic distribution: The ferns made their appearance in the early Devonian and reached a fairly high state of

[1] Oliver, F. W., and Scott, D. H., On Lagenostoma Lomaxi, the seed of Lyginodendron. Proc. Roy. Soc. London LXXI, p. 477, 1903. LXXIII, p. 4, 1904; also On the structure of the Paleozoic seed Lagenostoma Lomaxi. Phil. Trans. Roy. Soc. London, Ser. B., Vol. 197, p. 193, Pls. 4 to 10, 1904.

[2] Zeiller, R., Bassin houiller et Permien de Blanzy et du Creusot, Études des gîtes Minéreaux de la France, Fasc. II, Flore Fossile, Text et Atlas.

development in that period. They increased in numbers oı species and in individuals in the Carboniferous and while none of the typical

FIG. 50. — *1* Alethopteris serli (Brongniart); *3*, A. decurrens (Artes). These forms illustrate the different forms of the pinnules in this genus. (After Zeiller.)

Carboniferous species extended beyond the Permian other species of the same genera have occupied a prominent position in the world's flora during the Triassic and Jurassic periods and still others have

carried the succession to the present time. They have been found in probably every country in which plant remains are abundant

(4) THE SPERMATOPHYTES

The *Spermatophytes* include the two great groups of highly organized seed plants, the *Gymnosperms* and the *Angiosperms*. They are often called *Phanerogams* or "flowering plants."

GYMNOSPERMS

The Gymnosperms include a great variety of plants, from shrubs to large trees, and they have had representatives from middle Paleozoic time to the present. They are characterized by their *naked seeds*

FIG. 51. — Lonchopteris bricei (Brongniart) showing the terminal pinnules and the changes occurring in the pinnules with maturity. From the Coal Measures of France. (After Zeiller.)

in contrast to the Angiosperms which have the seeds *enclosed*. The main groups of *Gymnosperms* are (1) *Cycadofilicales*, (2) *Bennettitales*, (3) *Cycadales*, (4) *Cordaitales*, (5) *Gingkoales*, (6) *Coniferales*, and (7) *Gnetales*. Of these groups the Cycadofilicales, the Bennettitales, and the Cordaitales are all extinct.

(1) *Cycadofilicales:* As already mentioned in the discussion on

ferns, there have been found during this century numerous plants which were formerly thought from their frond character to be ferns but which have been grouped together to form the Pteridosperms because of the discovery of their seeds. They are believed to be the most primitive of the seed plants, and from them the modern Gymnosperms developed. They show a transition between the ferns and cycads and they differ from the ferns in having secondary wood. This secondary wood is still a Pteridophyte character in some groups although it is also a characteristic of the Gymnosperms. The *microsporangia* are similar to those of the ferns but the *macrosporangia* are very different since an ovule is developed. As the members of this group have been differentiated so recently and as there is so much uncertainty about which genera and species should be placed with the Pteridosperms and which with the ferns, it is impossible to state definitely their geological range. They appeared at least as early as the Upper Devonian, became extremely abundant in the Carboniferous, extended into the Permian and probably into the Mesozoic.

(2) *Bennettitales and* (3) *Cycadales: Bennettitales* is the name applied by some botanists to a group of extinct Mesozoic plants which are regarded as the ancestors of the living cycads. In his monograph on the fossil cycads, Wieland[1] stated that in the opinion of Scott and Zeiller the Bennettitales should not be regarded as a separate class and that his work has verified the opinion of these botanists and his own earlier expressed opinion. He had formerly believed that Cycadales should include the existing families Cycadeae and Zamiae forming the order Cycadaceae, and the extinct family Bennettiteae which might have the rank of an order.

The living forms of cycads are tropical plants and they occur in both the Eastern and Western Hemispheres. Common genera are Cycas and Zamia.

The family Cycadeoideae or the Bennettiteae have been reported from the Triassic, the Jurassic, and lower Cretaceous of America and they have a similar range in Europe and Asia.

The representatives, such as Zamites, of the living families of cycads have been found as far back as the Coal Measures.[2] They

[1] Wieland, G. R., American fossil cycads, Carnegie Inst. of Washington, p. 236, 1906.

[2] Renault, B., et Zeiller, R. Sur quelques cycadées houillères. Comptes rendus de l'acad. de Paris, 1886.

increased in numbers through the Permian and reached a maximum development in the Jurassic which is often spoken of as the "Age of Cycads." They have had a very wide geographical distribution.

(4) *Cordaitales:* The *Cordaitales* formed the main portion of the arborescent Gymnosperm vegetation of the later Paleozoic. They comprised rather slender trees which were of uniform size for 10 or 15 meters, but reached upwards of 30 meters in height and were crowned by numerous branches. The genus *Cordaites* (Unger) may

FIG. 52. — Cycadeoidea marshiana showing stages in fruit production as shown in branching species. (After Wieland, American Fossil Cycads.)

be taken as the typical representative of the group. The leaves are simple and are characterized by distinct parallel nervation, often becoming complex. They resemble those of the Cycads in exhibiting the characteristic mesophyll, and those of the Coniferae in the form of the leaf, which is long, usually rounded at the outer end and narrowing towards the base.

The stem and branches are provided with a large medullar sheath cut by transverse diaphragms of the pith. There is a thick cylinder of secondary wood.

In the structure of the ovule and the swimming sperms they resemble the Cycads and Gingkos which are the only living plants

with these sperms. Their structure has been studied in detail by Grand'Eury, and Renault, and to them chiefly we owe our knowledge of the reproductive organs.

Geologic and geographic distribution: The Cordaiteae appeared in the Devonian in America,[1] Europe and Australia. It seems possible

FIG. 53. — Cordaites showing the leaves and organs of fructification. (After Grand' Eury. Flore Carbonifére du Département de la Loire.)

that they may have lived as early as the Middle Devonian. They were abundant in the upper Coal Measures and continued into the

[1] Dawson, J. W., On Fossil Plants from the Devonian Rocks of Canada. Quart. Jour. Geol. Soc. of London, Vol. 15, 1859.

Permian, but it is not believed that they survived the close of the Paleozoic.

(5) *Gingkoales:* This order of Gymnosperms is represented by a single living species, Gingko biloba, found wild in China and cultivated by the Chinese and Japanese. The fossil forms of this group

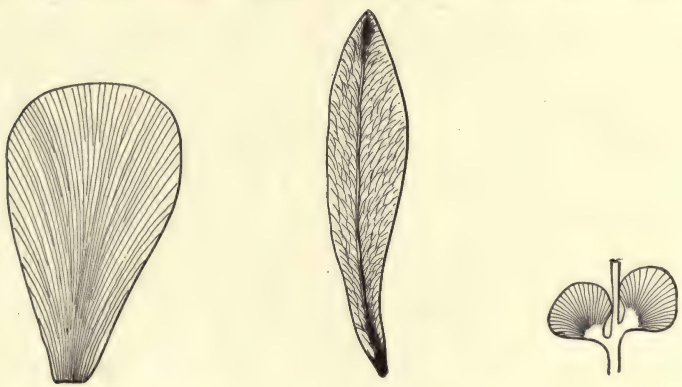
FIG. 54. — Walchia frondosa (B. Renault) showing small cones. From the Permian of France. (After B. Renault, Bassin Houiller et Permien, Études des Gîtes Minéraux de la France.)

have frequently gone under the name of the Salisburias. They have probably been derived from the Cordaitae and they were abundant in the Mesozoic, being mentioned as occurring in the Oolite and the Chalk of Europe, and in the Triassic and Jurassic of Australia.[1]

[1] Süssmilch, C. A., An introduction to the geology of New South Wales, pp. 164 and 175, 1914.

(6) *Coniferales:* This group of plants is so well known at the present day that they scarcely need a detailed description. They are characterized primarily by their cones although other plants, such as some of the Pteridophytes, may have cones of a certain kind. Most of these trees are evergreens, as the pines, hemlocks, spruces, and cedars but some, like the tamarack, are deciduous. Most of them have needle leaves which are specially adapted to the rigors of northern climates. The stem is a single, central stalk extending to the top of the tree.

There are two families (1) *Taxaceae* and (2) *Pinaceae.* The members of the former family usually have fleshy seeds and ovules freely



a. *b.* *c.*

Fig. 55. — Leaves of plants from the Glossopteris flora. (*a*) Gangamopteris. (*b*) Glossopteris. (*c*) Rhacopteris.

exposed and those of the latter family have dry seeds and ovules concealed by scales.

The Pinaceae may again be divided into four groups well represented by living forms: (1) *Abietineae*, including pines, spruces, hemlocks, firs, cedars, and larches; (2) *Taxodineae*, including Sequoia and Taxodium (bald cypress common in our southern swamps); (3) *Cupressineae*, including the arbor vitae, and the juniper; (4) *Araucarineae*, including the Araucarian pines so frequently seen in New Zealand.

Representatives of the Coniferae extend back into Devonian beds, but it is not always easy to place the fossil forms in the groups mentioned above and, furthermore, the wood of the Coniferae may in

FIG. 56. — Leaves illustrating the development of the modern types of plants in the later geological periods. *a*, Macrotaenopteris magnifolia (Rogers), Triassic coal beds of Virginia (Fontaine); *b*, Gingko digitata (Herr), Jurassic; *c*, Cinnamomum Lesperium (Knowlton); *d*, Aralia veatchii and *e*, Rhamnus? Williardi (Knowlton), Upper Cretaceous; *f*, Fagara, catahoulensis major (Berry) and *g*, Ulmus floridana (Berry), Oligocene; *h*, Quercus chapmanifolis (Berry), Miocene (U. S. Geol. Survey.)

some cases be confused with that of the Cordaites as there is a close relationship between the groups, Cordaites and Coniferae. The Taxaceae do not seem to have extended backward beyond the Jurassic. The Cupressineae have been found as far back as the Jurassic. The well-known extinct genus Voltzia probably belonged to the Araucarineae and extended back into the Permian. Walchia is a conifer from the Permian. The Sequoias have been found from the early Cretaceous onward and were abundant in the early Tertiary. Taxodium probably extended from the Oligocene to the present. The Coniferae have been widely distributed over the globe.

THE ANGIOSPERMS

This great group of plants, representing the climax in plant evolution, was ushered in with the Cretaceous period. They have developed so rapidly and they now occupy such an important and common place in the living vegetation that any attempt to describe them here would be futile. Their representatives are found in every formation where plant fossils occur since the beginning of the Lower Cretaceous period, and they now outnumber the Gymnosperms several hundred times. The common trees, outside of the Conifers, belong to this group, as do the grasses and the other common flowering plants with which everyone is so familiar.

CHAPTER VIII

STRUCTURAL FEATURES OF COAL SEAMS

Thickness of Seams

Coal beds vary from a fraction of an inch to the enormous thickness of 266 feet. At Morwell, Victoria, Australia, there are three seams of brown coal which are 266, 227, and 166 feet respectively, in thickness. They are the thickest so far known in the world. A drill hole 1010 feet deep passed through 780 feet of coal. Other notable beds are the Grande Couche of Commentry, central France, which is 60 feet thick, and the Mammoth seam of the anthracite region of Pennsylvania, which in the Southern Field reaches 50 feet in thickness. Seams in Styria and Manchuria exceed 100 feet in places. Most seams vary rather rapidly in thickness from place to place, the Pittsburgh bed of the Appalachian province being probably the most remarkable exception to this rule. This seam has been traced over an area of more than 2100 square miles with an average thickness of over 7 feet. Its total original area has been estimated at about 30,000 square miles. The irregularities in the thickness of seams are due chiefly to the structures known as "partings," "pinches" or "squeezes," "swells," "horsebacks," "rolls," "clay veins" and "cut-outs" and to igneous intrusions.

Partings. — A seam may be divided into several thinner seams or "splits" by partings of clay, shale, slate, or sandstone, (Fig. 57). For example, the Mammoth seam, which reaches a thickness of 50 feet in the eastern part of the Southern Field is divided into three splits at the western end, averaging about 10, 12 and 15 feet respectively, in thickness, with partings of slate between them running from 10 to 30 feet in thickness. These splits would be regarded as individual seams were it not for the fact that they can be traced into the main seam to the eastward. Other seams are known in which the number of splits is very much larger than in the case cited.

The splits are due to the fact that while the vegetal matter is being laid down in the swamp or open body of water there are periods

when clay or sand is brought in by water from the surrounding lands and carried out over the vegetal matter. The deposit of sediment grows thinner as it extends away from the dry land and some distance from the edge of the basin the deposition of vegetal matter goes on without interruption so that a continuous coal seam results, whereas closer to the edge the seam is interrupted by these bands of sediment. The number of partings will depend upon the rate of change in level between the surrounding land and the basin, or upon the variations in climate. A sinking of the basin where the vegetal matter is being deposited or a rise of the surrounding land will cause sediment to be

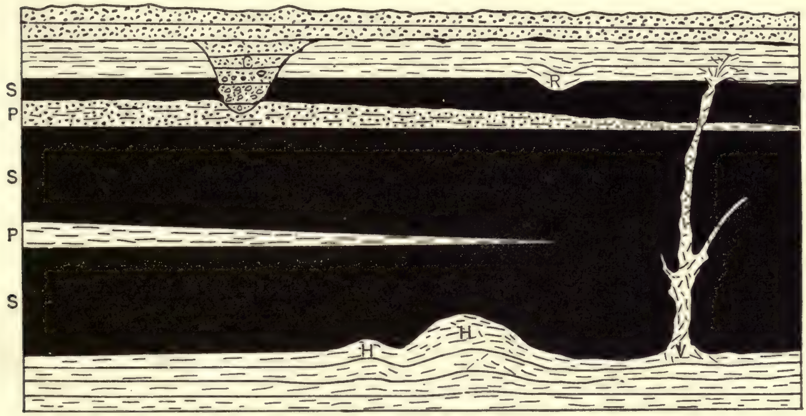


FIG. 57. — Diagram illustrating: C, cut-out; H, horsebacks; P, parting; R, roll; S, split; V, clay vein.

carried out by streams farther from the edge of the swamp or other basin than it was formerly, while a change to a wetter climate may also cause greater erosion of the land and consequently a more extended deposition of sediment over the vegetal matter in the swamp.

"Pinches" or "squeezes," and "swells." — These are terms applied to sections in the seam where it has become constricted by the squeezing in, or extended by the bulging out of the overlying or underlying rocks. They are due to pressure applied to the seam during the folding and other movements of the enclosing strata and they may accompany the formation of "horsebacks" and similar structures.

"Cut-outs." — This is a term applied by miners to any place in the seam where the coal ends abruptly on account of faulting, squeezing, or erosion. It may be used in a more restricted sense for the case where part of the bed has been removed by erosion, (Fig. 57). It often happens that a coal-bearing formation suffers erosion and a stream cuts a ravine through one or more beds of coal. This ravine may be filled later by sand or clay carried in by the stream, or a glacier passing over it may fill it with drift consisting of a mixture of clay, sand and boulders. A fine example of the latter phenomenon is found in the Anthracite Field of Pennsylvania. Before the glacier appeared in this district the Susquehanna River flowed in a channel

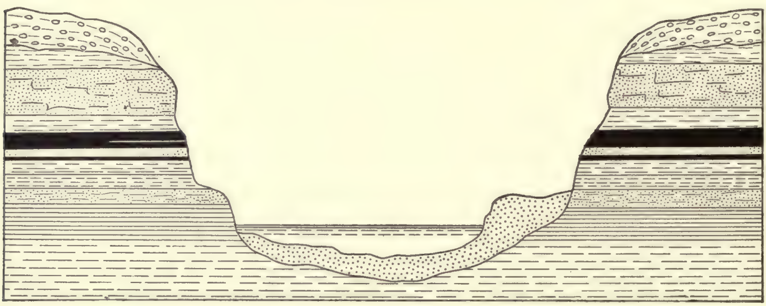


FIG. 58. — Gorge of Des Moines River at city of Des Moines illustrating how a cut-out may develop. (From Iowa Geol. Survey.)

between Nanticoke and Pittston. During Pleistocene time the glacier moved southward across this channel, which became filled with glacial drift. The river was thus forced to carve out a new channel for itself after the glacier melted away. It has also been suggested that this abandoned channel might have been gouged out by the glacier as fiords are deepened. The old channel has been well outlined as it has caused much trouble in mining, owing particularly to the large amount of water contained in the sand and gravel and the bad condition of the rocks along its edges.

"Horsebacks," "rolls," and "clay veins." — All of these names have been used more or less loosely for the same structures in coal mines in different localities. The term "horseback" among the coal miners is used to indicate some foreign body in the coal seam in much the same general way as "horse" is used among the metal miners to indicate a mass of rock in the lode. It probably

arose from the general rounded form, which is more or less characteristic of these structures and which suggests the arched back of a horse. The German miners use the word " horst " in much the same way as " horse " is used among the miners in this country.

The names " rolls " and " swells " are very appropriate terms for these structures because in some mines these masses of rock resemble nothing more closely than the waves on the sea when running as a ground-swell. The reason for confusing the " clay vein " with the horseback is doubtless due to the fact that the former in many places is an offshoot from a rounded mass of clay similar to a typical horseback, (Fig. 57).

Several theories have been offered to explain the origin of horsebacks and it is possible they have been formed in at least two ways. One theory, advanced by mining men in some coal fields, is that they were formed by streams flowing into the swamps where the vegetation giving rise to the coal was being laid down.[1] These streams would bring in clay or sand and build up long narrow ridges of sediment which would become buried under vegetal matter as the formation of the coal bed progressed. The rolls in the roof are explained as due to a stream cutting a channel down into the coal seam, this channel later becoming filled with sediment. While this explanation may account for a few of these structures it will not account for the great majority of horsebacks, as they are undoubtedly due to compression of the seam and enclosing rocks, which produces small folds in either the roof or floor of the seam or in both. When pressure is applied to the floor it buckles up into the coal, which is less resistant than the bottom rock and, in the early stages of its development, much more plastic than the underlying rocks. Likewise when pressure causes the draw slate to buckle in the roof of the seam it bends down into the coal (Fig. 57). A very fine illustration of the occurrence of these structures is seen in the Pittsburgh seam in the vicinity of Connellsville, Pennsylvania.[2] They rise from 6 inches to as many feet above the general level of the floor of the seam and resemble waves spread over the floor of the mine (Plate IX). The seam is everywhere constricted above them except in one or two

[1] J. F. Blandy, On evidence of streams during the deposition of the coal, (horsebacks). Trans. Amer. Inst. Min. Eng., Vol. 4, p. 113, 1875.

[2] Moore, E. S., "Horsebacks" in Oliver No. 3 Mine. Coal Age, Vol. 3, p. 566, 1913.

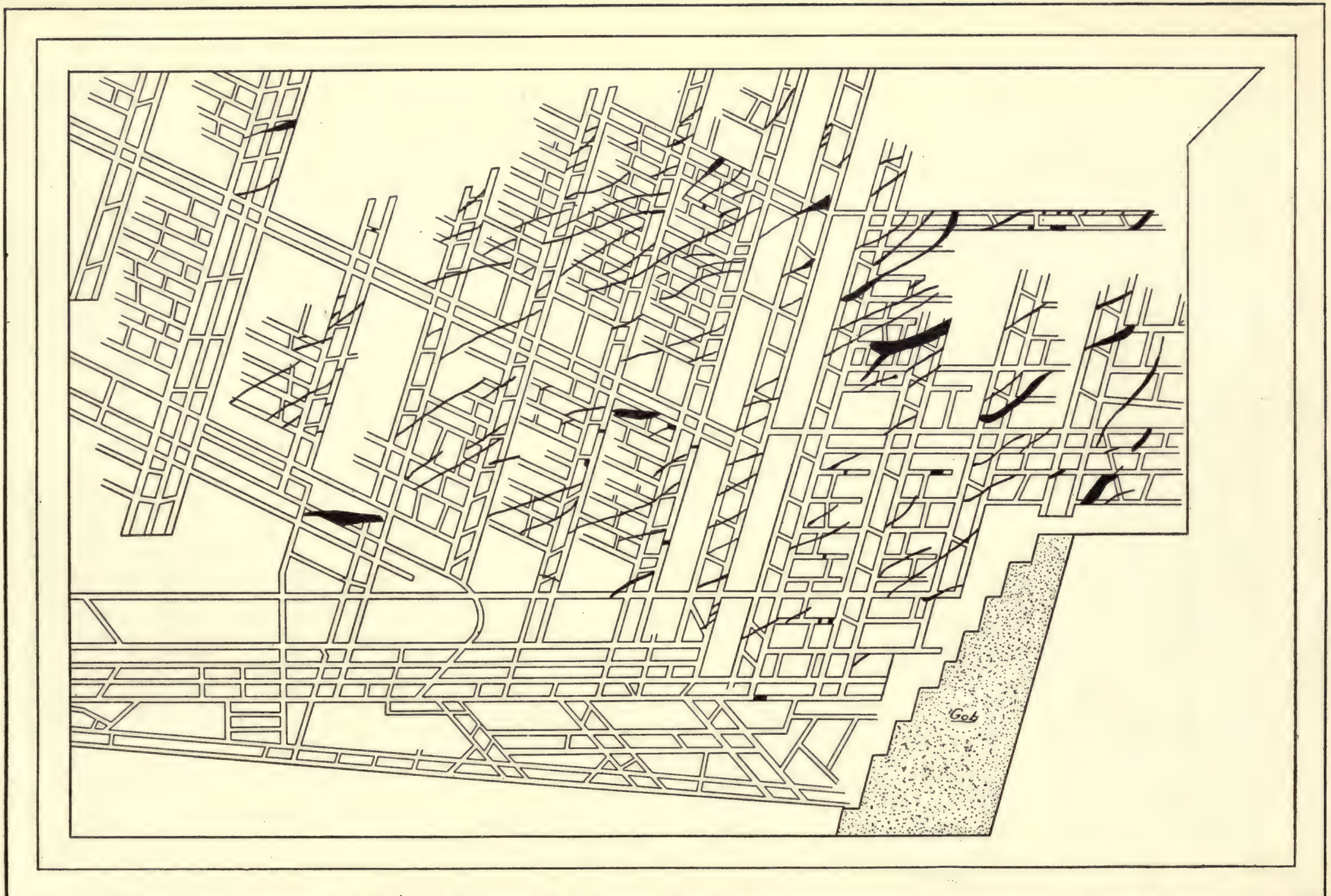


PLATE IX. — Horsebacks, indicated by shading, in Oliver No. 3 Mine, Pa. Their arrangement is practically parallel to each other and to the strike of the Measures in that area.

places noted, where the roof slate is bowed up above the elevation in the floor. The rolls often show lamination in the sediments where the beds have been bent and in many of these there are bunches of pyrite crystals which have collected there because the structure directed the circulating, iron-bearing waters into these little anticlines.

The horsebacks are not uniformly distributed over the floor of the mine because the rocks are not uniformly resistant and therefore they buckle in some areas and resist buckling in others. Where there is one roll there are usually two or more adjoining it, as in the case of waves on water, due to the fact that a large anticline should normally have small ones on either side where it dies out. These smaller folds result from irregularities in the strength of the bed and from the different angles at which the force is applied as the larger fold develops. That these structures are not deposits made by streams is proven by the fact that they often occur entirely away from the border of the swamp in which the coal vegetation was laid down.

The coal basins as they now exist are not identical in size or shape with the original basins but have resulted from the folding of the coal measures into anticlines, where there were originally small elevations, and synclines, where there were originally small depressions in the strata. With subsequent erosion of the anticlines the synclinal basins have been separated from each other. Thus it will be seen that one of these basins may be near the center of the great swamp in which the vegetal matter was originally laid down and the horseback may show no connection with the land at the border of the original basin.

It is evident that a direct relation may be found between the orientation of the horsebacks and the direction of the main structures of the basin. Following the general principles of structural geology it is known that if a small fold occurs on the flank, in the trough, or on the crest of a larger fold the axis of the minor fold will be in the same direction as the strike of the rocks at that particular point in the larger fold. It was found to be true at Oliver No. 3 mine, mentioned above, that the axes of the horsebacks follow the strike of the rocks forming the larger basin at the point where they occur, and inquiries in various other mining regions where horsebacks are common elicited answers which go to strengthen this assumption for the arrangement of these structures in all fields. According to this principle the long axes of the horsebacks in a pitching synclinal basin would form, if plotted on

a map of the basin, an elliptical zone around the deepest point in the basin. As the center of the basin is approached the arrangement of the structures will become much less regular owing to the confusion of forces which are acting from various directions on the rocks in the center of the basin. The establishing of this relationship between the direction of the horsebacks and the larger folds in the coal basins has a practical bearing. It should become possible, as our knowledge of these structures increases, to predict the general direction in which the long axes of the horsebacks will lie and, when the arrangement of these is known, the entries and butts in the mine may be planned in such a way as to avoid as much as possible the cutting of these ridges. If one must be cut it may be cut along its shorter axis.

A " clay vein " is a body of clay which fills a crevice in a coal seam, (Fig. 57). It is usually roughly tabular like an ore vein, but in many cases it branches in an extremely complex manner, sending stringers out in all directions through the coal. It originates where the pressure on the floor or roof of the seam, or on both, is sufficiently great to force plastic clay into small fissures and in many cases enlarge them. The clay often rises as a mound on the floor of the seam so that it resembles a horseback and if there be a crack in the overlying coal it rises from the mound as a vein. In some localities the miners use the word " spar " for a small clay vein.

"Bell," "pot," "kettle." — The terms "bell," "pot," and "kettle" are often used for a roughly cone-shaped or rounded mass of slickensided rock which falls from the roof of a seam, sometimes causing serious accidents to the miners. These bodies are also known as " camel-backs " and " tortoises." They are, in most cases, concretionary structures containing pyrite, iron oxide, iron carbonate or calcite mixed with clay or slate and they separate rather freely from the roof slate. This ready separation is apparently often due to previous movement in the strata as the bodies frequently show slickensided surfaces indicating that there has been slipping of the surrounding rocks over the concretionary masses. In addition to the concretionary bodies which form these structures in the roof there are certain harder or denser patches of clay or sandstone, which separate from the adjacent rocks and fall from the roof, (Fig. 59). Rounded masses of igneous rock and casts of trees occur in the upper part of the coal bed in some regions and they fall freely from the roof.

These structures may all go under the names mentioned above if their shape, in the opinion of the miner, happens to correspond to that of any of the above-named bodies.

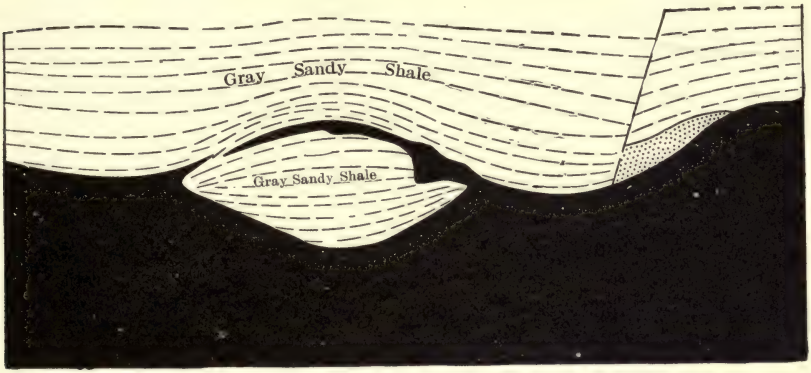


FIG. 59. — Small coal stringer, Paradise Mine Duquoin, Ill. (From Bull. of the Ill. Geol. Survey, University of Ill. and U. S. Bur. of Mines.)

Folding in Coal Beds

In any study or discussion of folds two terms, *dip* and *strike*, are much used. The dip is the angle which the bed makes with a horizontal plane, or in other words the inclination of the bed to a horizontal plane.

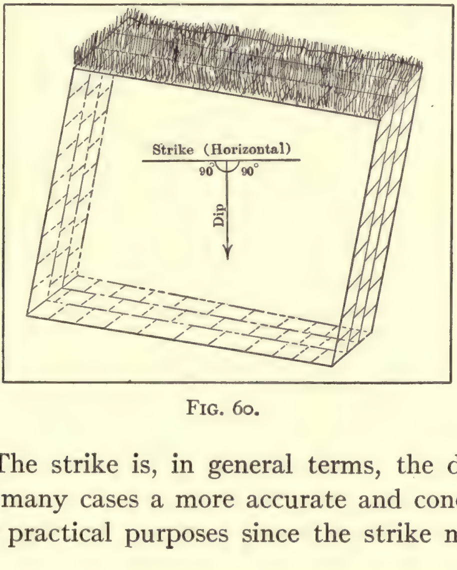


FIG. 60.

The strike is, in general terms, the direction of the outcrop, but in many cases a more accurate and concrete definition is necessary for practical purposes since the strike must sometimes

be determined in the bottom of a mine shaft or elsewhere where only a very small area of the stratum is exposed. In such cases the strike is represented by a horizontal line on the face of the bed or in other words *the strike is the line along which the bed intersects a horizontal plane.* This line may be found by using a clinometer or level and its direction may be determined with a compass. The direction of dip is always at right angles to the direction of strike, (Fig. 60). The pitch is the inclination of the axis of a fold to a horizontal line. The pitch and dip correspond at the extreme ends of a pitching anticline or syncline, but in no other portion of the fold. Among miners the term pitch usually refers to the inclination in the opposite direction from that of the dip. It may be expressed as "up the dip."

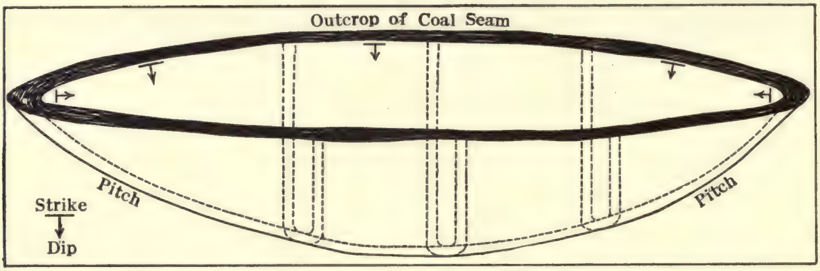


FIG. 61. — Stereogram of a pitching syncline showing the relation between pitch and dip in the coal seam.

A fold is a flexure in rocks, and it usually consists of two sections, the *anticline*, or crest, and the *syncline*, or trough, of the wave-like structure. The axis or the central line of the anticline or syncline is never horizontal for great distances but bows down at the ends in the anticline and up at the ends in the syncline, giving *pitching* anticlines and synclines, (Fig. 61). This explains why a coal bed "cropping" around the edge of a basin forms a sort of ellipse. Folds may be *closed* or *open*. In an open fold the limbs, or the beds on the sides of the flexure, are not squeezed together, while in the closed fold they are. An *isoclinal* fold is one in which the limbs are parallel to each other. An *overthrust* fold is one in which the beds are bent beyond the vertical position and such a fold may grade into a thrust fault where the compression becomes sufficiently great to break the rocks and push them along the fracture. A *monoclinal* fold is one in which

the beds dip in one direction only within a given area. When a number of small, or secondary anticlines occur on a large anticline the structure is known as an *anticlinorium*, and if small synclines occur on a large syncline the resulting structure is a *synclinorium*.

Folding has a great influence on coal seams, in pinching them off as in horsebacks, bulging them out, and squeezing them so that in some cases they are partly turned into graphitic carbon. The pressure is less in the crest of an anticline than in the sides, therefore the coal and soft rocks like clay are crowded into the anticline and the

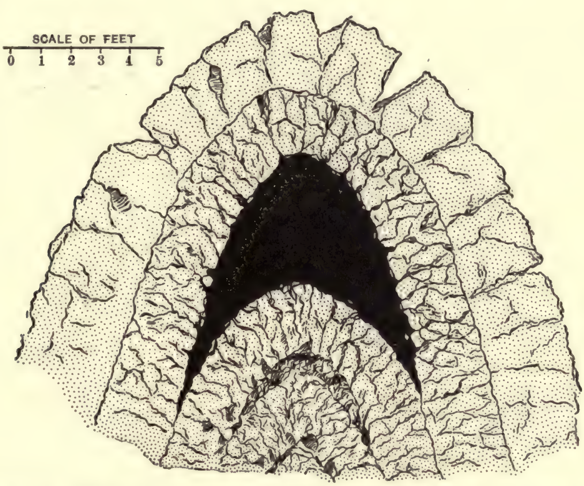


FIG. 62. — A sketch by W. R. Crane of an anticline in Alaska, in which the coal seam has been pinched off on the limbs of the fold and crowded into the crest of the anticline where the pressure is least.

seam becomes thicker in the crest but thinner on the limbs, (Fig. 62). Where the folding is intense there is always considerable slipping of beds over one another, and the folds pass over into faults if the movement becomes intensive. It is the heavy, strong beds or so-called *competent* beds in a formation, which always control the folding as they compel the softer and weaker beds to fold themselves into such forms as they may under the circumstances. Cases are even known where a certain bed has been highly folded although it lies between other beds which show very little evidence of folding. The latter beds must have slipped over each other and thus relieved

the pressure without crumpling, while the former was compelled to wrinkle up to accommodate itself to the new conditions. An interesting example of this in the English coal fields is pointed out by Strahan (Fig. 63). This may have a bearing on the origin of anthracite in showing that the lack of crumpling in the strata adjacent to the coal does not always prove the absence of great compressive stress in the coal.

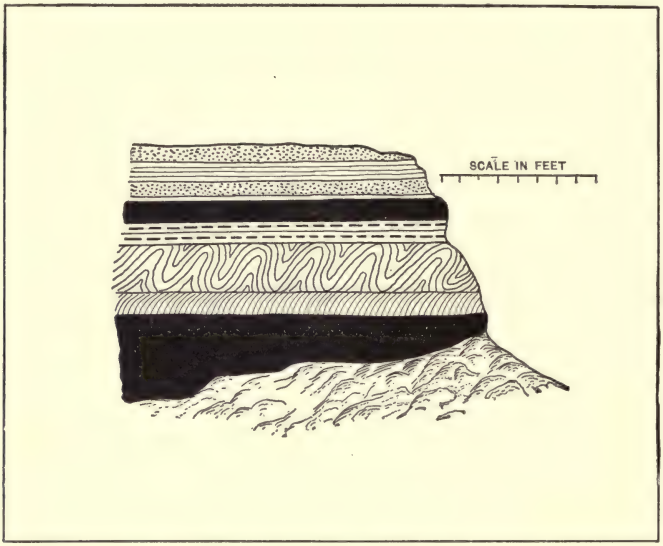


FIG. 63. — Contortion in a parting between two coal seams leaving the beds above and below apparently unaffected. Tir-bach. (After Strahan, Geol. Survey of England and Wales.)

Faults

A fault is a fracture in the earth's crust along which the rocks on one side have moved relatively to those on the other side. There are three relative movements which may occur: (1) The rocks on one side of the fracture may remain stationary and those on the other side move up or down. (2) Those on one side may move up and the others down. (3) The rocks on both sides may move in the same direction but those on one side must move more than those on the other before a fault results. The movement may also be along horizontal or oblique rather than along vertical lines.

Certain names are used to designate the various real and apparent motions in a fault. The fracture along which the slipping occurs is usually called the *fault-plane* but the term *fault surface* is a better word because the fracture in many faults departs widely from a plane and it is sometimes a regular curved surface. The term *displacement* is used in a general way to describe the relative movement of the rocks on this surface whether the movement be in a horizontal, a vertical, or an oblique direction. In Fig. 64, *EF* is the *displacement.* The vertical distance *ED* the beds are displaced, is called the *throw*, the horizontal distance *FD* the *heave*. The angle *FED*, which the fracture makes with the vertical is the *hade*. When the rocks on the *upthrow* side of the fracture project above those on the *downthrow* side this projection *AC* is known as the *fault scarp.* During the movement on the fault surface the rocks are often smoothed and polished. This smooth surface is a *slickenside* and when clay results from the grinding up of the rocks during movement it is called *gouge*, or *selvage*. If the rocks along the fracture are broken up into angular fragments the resulting material is known as a *fault breccia.*

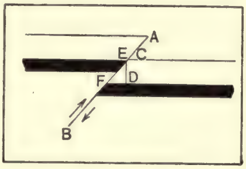


FIG. 64. — Diagram illustrating a thrust fault and fault nomenclature.

There are two main types of faults: (*a*) the *gravity* or *normal* fault, and (*b*) the *thrust* fault. In the former the overhanging side

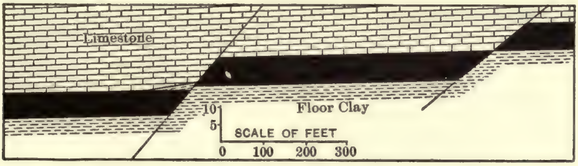


FIG. 65. — Sketch of faults in main entry near parting. Southern Coal, Coke and Mining Co., Mine No. 7, New Baden, Clinton County, Ill. (From Bull. of the Ill. Geol. Survey, University of Ill. and U. S. Bur. of Mines.)

or hanging wall side has moved downward towards the center of the earth as a result of tension or stretching in the earth's crust, and in the latter the overhanging side has moved upward relatively to the other side as a result of compressive force. Igneous activity may sometimes exert an upward pressure and produce thrust faults. Figure 65 is an example of a normal fault and Figure 64 of a thrust

fault. There are also various names used by the miners to indicate the nature of faults such as " shove " fault and " slip " fault. In the former, one body of rock has been pushed into another and the latter term is frequently used for a fault which lies nearly parallel to the bedding.

In many coal fields faults are a source of great difficulty to the miner, but other fields are almost entirely free from them. In some faults the seam is only *thrown* a few feet but in others the displacement may be several thousand feet. Thrust faults show the greater maximum displacement and this may reach many miles in the large mountains. It may be considered a general rule that the faults in any particular basin will be practically all normal or all thrust unless it can be shown that they have originated during at least two distinct periods of faulting.

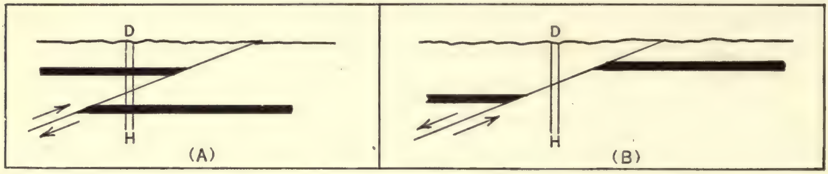


FIG. 66.— Diagrams showing how in (A) a drill hole may pass through the same coal seam twice because of thrust faulting and in (B) it may miss the seam entirely in the gap resulting from normal faulting.

The effects of faulting on prospecting are very great. A concealed seam may be brought to the surface or a seam at one time exposed may be faulted and eroded so that it no longer comes to the surface. A seam may be duplicated by faulting so that a drill hole will pass through it twice, (Fig. 66 (A)) or a gap may be produced so a drill will pass between the two portions of the seam without indicating its presence, (Fig. 66 (B)). If a fault cuts transversely through a syncline the outcrops of the seam on the sides of the syncline after erosion has occurred will be closer together on the *upthrow* side of the fault than on the *downthrow* side, while the opposite will be the case if the fault cuts an anticline.

It should be borne in mind that the older rocks will always be exposed on the *upthrow* side of the fault if the area has been eroded since faulting. In very few cases are faults so recent that the faulted rocks

have not suffered erosion and in most cases all evidence of the fault scarp has been removed. There is usually, therefore, little evidence of the presence of the fault on the surface unless there be a marked

FIG. 67. — A large fault in the Coal Measures near St. Etienne, France. (Photo by E. S. Moore.)

difference in the rocks on opposite sides of the fracture. In some places a sandstone may be brought opposite a shale, a shale opposite a limestone or a non-fossiliferous rock may be brought into juxtaposition to a fossiliferous rock, or a sedimentary rock to an igneous rock. There are many features which may be used by the geologist to distinguish the rocks on opposite sides of a fault and thus detect its presence.

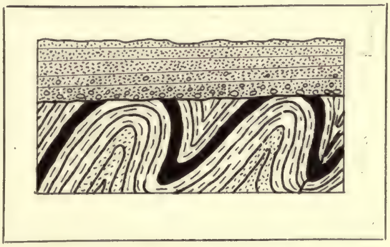


FIG. 68. — Diagram illustrating a great unconformity by folding, erosion and subsequent deposition.

Unconformities

An *unconformity* is an interruption in the continuous deposition of sediments in any locality. The presence of this hiatus, or break may be indicated by one or more of a number of factors among which are the following: (1) A sudden change in the character of the fossils found above or below the

horizon where the unconformity occurs; (2) Folding or faulting of the rocks below the unconformity while those above remain undisturbed; (3) Erosion of the underlying rocks before the later rocks were laid down upon them. This is illustrated in Figure 57 where the cut-out occurs. In Figure 68, the effect of both folding and erosion is seen, as the coal-bearing formation was folded and eroded before the later formation was laid down.

Igneous Intrusions

In regions of igneous activity such as those of the western states, Alaska, parts of Great Britain and some other countries, the coal seams have been cut by igneous intrusions of many forms. The

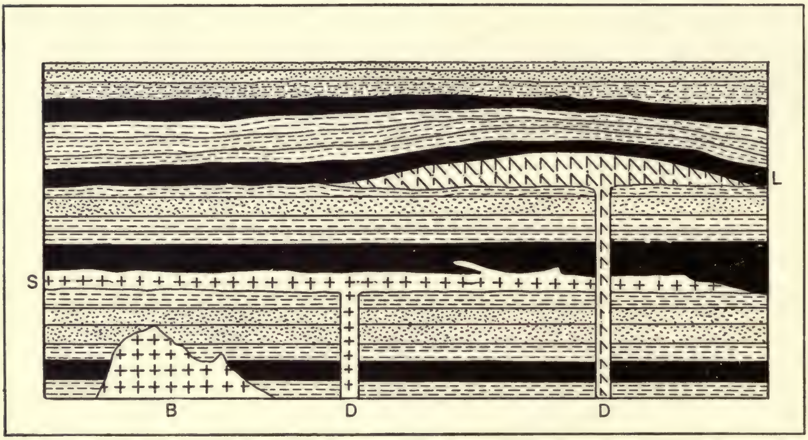


FIG. 69. — Diagram illustrating the different forms which igneous rocks may assume in intruding coal measures. B, a portion of a batholith; D, dike; L, laccolith; and S, sill. Such intrusions produce natural coke and otherwise alter the coal adjacent to them.

different forms which these intrusions take are illustrated in Figure 69. If a fracture becomes filled with liquid rock it is known as a *dike*; if the liquid spreads out along a bedding plane in the sediments and solidifies as a tabular mass of great areal extent compared with its thickness it is known as a *sill*. If it forms a lens-shaped body and arches up the overlying strata it is a *laccolith*, while a large, irregular mass is a *batholith*. Other bodies which have great vertical dimensions compared with their lateral, are known as *bosses*, *necks* or *plugs* and

if the liquid rock reaches the earth's surface and flows out over the surface it is a lava *flow*, or *sheet*.

Some of the intrusions in coal seams are extremely complex in form. A good example is that figured by Jukes from the South Staffordshire Coal Field in England, (Fig. 70). Intrusions of less complexity may be seen in the Newcastle Field of Australia and in some of the western states. As a rule the dark basic rocks, such as traps, are capable of producing more complex intrusions than are the lighter-colored, acid rocks like granites because the liquid is less viscous and it more readily enters intricate fractures.

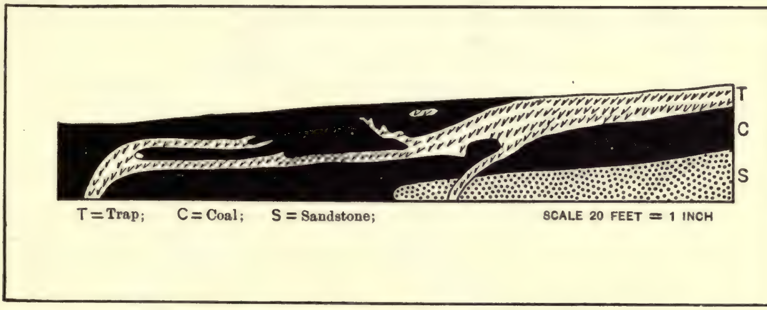


FIG. 70. — Complex intrusion in coal seam. (After Jukes, Geol. Survey of England and Wales.)

The most important effects of igneous intrusions outside of the difficulties they often create in mining operations is the coking of the coal. (For a discussion of this subject see Carbonite or Natural coke.) A dike usually affects a very limited area but a large sill or laccolith may extend for a long distance parallel to a seam, converting practically the whole bed into coke, as some of the sills have done in Colorado and New Mexico. There is usually a relation between the thickness of the igneous body and the thickness of the coked zone, one being directly proportional to the other, but this relation will not always hold any more than it does in the case of the width of the metamorphosed zone adjoining intrusions in other rocks. The temperature of the molten rock, its gas content and other physical conditions at the time it reaches the coal have great influence on its coking effects.

Concretionary Bodies in Coal Seams

The concretionary bodies found in coal and in the adjacent rocks commonly go under the names of "coal apples," "coal balls," and

"sulphur balls." The coal apples, or coal balls consist chiefly of calcium carbonate, magnesium carbonate, iron carbonate, or iron oxide, with varying amounts of clay, shale or sand. Small amounts of calcium phosphate, carbonate of manganese and other constituents are often present. The sulphur balls consist of iron sulphide (FeS_2) in the form of pyrite often known as "fool's gold" or marcasite, mixed with clay or sand in different proportions. In some cases a little free sulphur occurs as a coating owing to oxidation of the pyrite. All these bodies are concretions in the strict sense of the term. They have grown up as a result of the chemical deposition of these various substances around some central point and they show a concentric arrangement of the material varying very greatly in degree of perfection. They are irregularly distributed through the coal seam, or the shales above and below the coal, or they project from the coal into the adjacent rocks.

In addition to these concretions there are other bodies consisting of coal, which strongly resemble concretions in appearance but which are not true concretions since the material composing them has not been precipitated from solution around a nuclear point. They resemble somewhat the so-called "physical" concretions of some writers as distinguished from chemical concretions, and they are believed to have been formed as a result of fracturing and movement in the bed. This type is common in Colorado where the coal is known as "nigger-head" coal.

Calcareous concretions. — These bodies are abundant in the Coal Measures where limestones are associated with the coal-bearing formations. They have been described in detail by Stopes and Watson[1] for the coal fields of England and some of the Continental fields. They occur in large numbers in those coal seams, the roofs of which contain a marine fauna consisting of goniatites and lamellabranchs. The waters in which the vegetal matter forming the seams was laid down were rich in salts of calcium and magnesium. The roof shales contain plant remains which differ considerably from those in the coal seams, thus suggesting that the vegetal matter in the overlying rocks was drifted to its present location while that which composed the seam

[1] Stopes, M. C., and Watson, D. M. S., On the present distribution and origin of the calcareous concretions in coal seams known as "coal balls." Phil. Trans. Roy. Soc. London. Series B, Vol. 200, pp. 167–218, 1909.

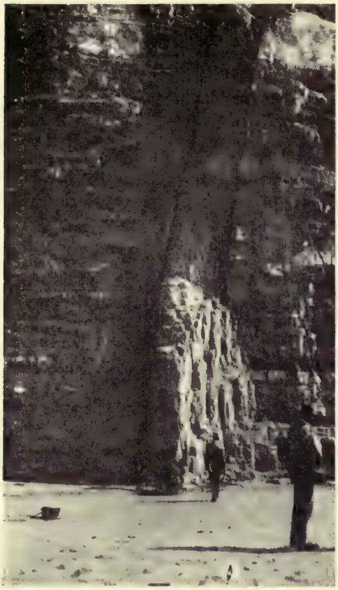


FIG. 71. — Vertical dike in Coal Measures, Australia. (Photo by E. S. Moore.)

FIG. 72. — Peculiar effects of shearing in coal. Specimen in Muséum National d' Histoire Naturelle, Paris From Northern France.

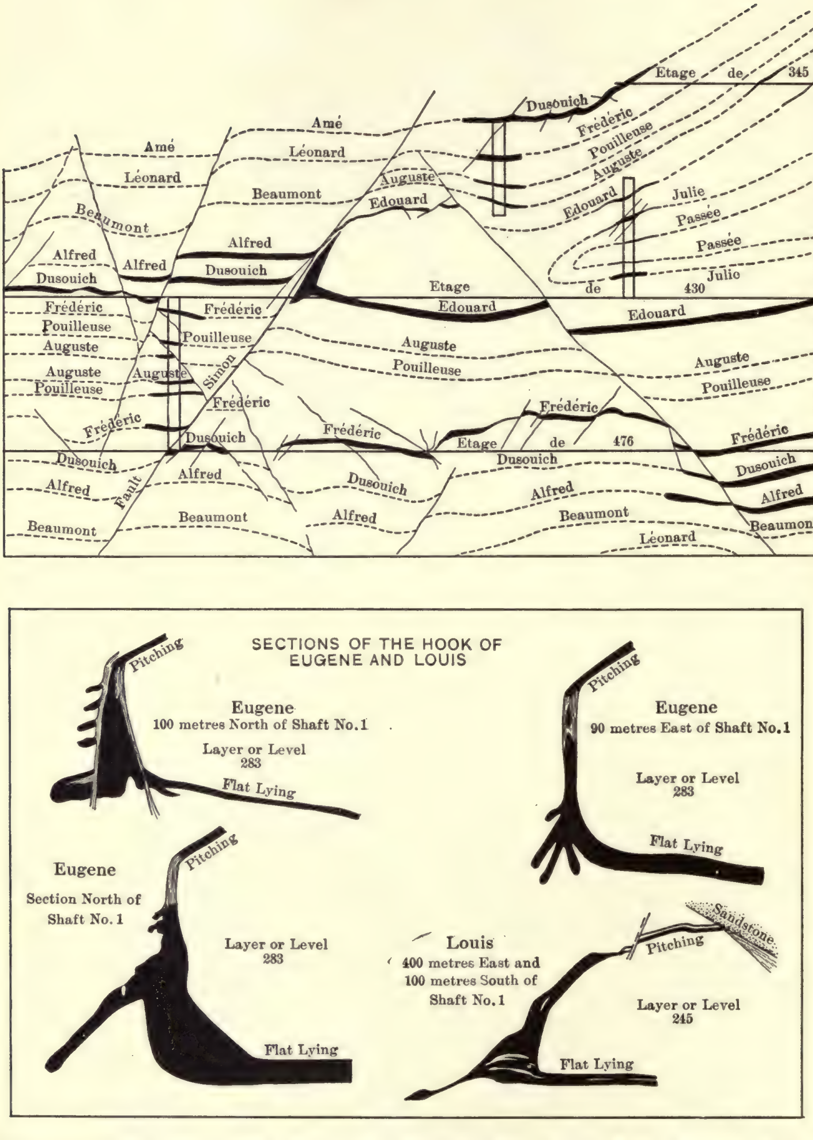


FIG. 73. — Very complicated structures resulting from faulting and squeezing in the coal seams of Northern France. The dark areas are sections of the seams. (From the Publications du Service des Topographies Souterraines; Bassin Houiller du Pas-de-Calais.)

grew in place. This might be the result of the deposition of plant remains in brackish water along the sea coast followed by a transgression of the sea over this material with the deposition of marine fossils in calcareous strata. Jeffrey[1] considers that the coal balls indicate that the vegetal matter enclosed in them was transported rather than developed *in situ* because he has found fragments of charcoal associated with other remains of plants in the same concretion. The material in the concretions differs from ordinary coal in the absence of the large proportion of spores which are found in the latter.

These " coal balls " almost everywhere contain remarkably well-preserved plant remains, indicating that they were formed about the time the plants settled to the bottom of the body of water and before they had an opportunity to decompose and become macerated. It is not necessary, as some writers have suggested, to invoke the preservative properties of saline water to account for their preservation. The perfect sealing conditions provided by the accumulation of mineral matter above the plant have been responsible for their complete preservation, and the finer structures of the plants may often be recognized in these concretions when they are not preserved at all in the adjacent coal. In some cases a plant stem may extend out into the surrounding coal. A concretion may be partly in the coal and partly in the roof slate, and laminations of the roof slate may pass through some of the concretions.

Another evidence that the concretions have formed early in the history of the coal seam, in addition to the preservation of the plant structures, is that the vegetal matter has been squeezed down around the balls while they have been scarcely compressed. They must have been in existence before the compression of the vegetal matter occurred, and the presence of slickensides shows that the coal and accompanying rocks were squeezed around them. It is only reasonable to suppose that these concretions were formed on the bottom of the marsh in which the vegetal matter grew and that they may have originated by the action of algae or other low forms of plants causing precipitation of calcium carbonate, as many calcareous concretions originate at the present day. As they grew, fragments of plants came in contact with them and were enclosed. In the case of the iron-carbonate concre-

[1] Jeffrey, E. C., Petrified coals and their bearing on the problem of the origin of coals. Proc. Nat. Acad. Sci., Vol. 3, pp. 206–211, 1917.

tions it is possible that they resulted from the reaction of ferrous sulphate and calcium carbonate in the presence of carbon dioxide. If the supply of carbon dioxide were insufficient, limonite would have

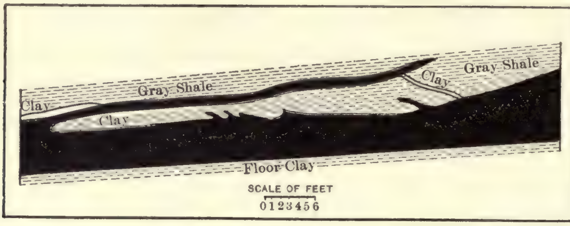


Fig. 74. — Coal stringer, Brilliant Coal and Coke Co. Horn Mine Duquoin, Ill. (From the Bull. Ill. Geol. Survey, University of Ill. and U. S. Bur. of Mines.)

formed instead of siderite and in the presence of hydrogen sulphide iron pyrite would have been precipitated to form sulphur balls. As to the agent causing precipitation of the iron compounds the iron

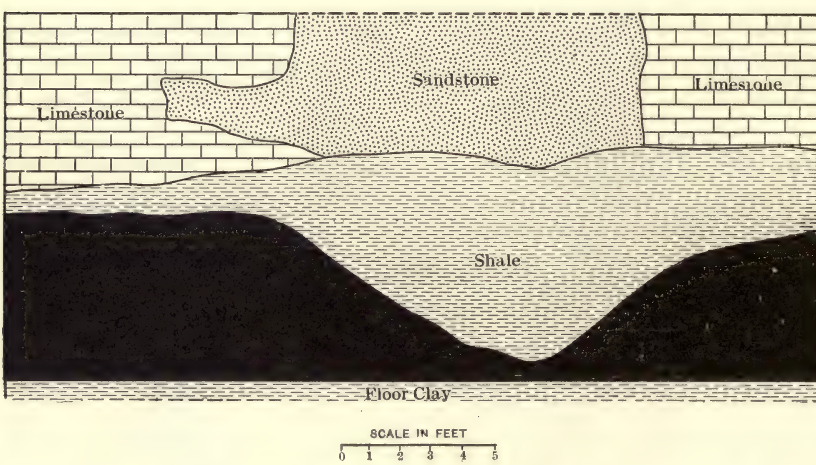


Fig. 75. — Roll in roof, Madison Coal Corporation Mine No. 6, Divernon, Ill. (From Bull. Ill. Geol. Survey, University of Ill. and U. S. Bur. of Mines.)

bacteria may have played a part or the balls may be replacements of calcareous nodules.

In size these balls may vary from minute nodules, less than an inch in diameter, to bodies several feet in diameter. One ball about 4

feet in diameter and estimated to be of about 2 tons weight was found in a mine at Shore, England, and it almost completely cut out the coal seam. The balls are usually roughly spherical and some large ones are made up of several smaller concretionary centers cemented together by carbonate and carbonaceous matter.

The analysis of the calcareous nodules according to Stopes and Watson showed calcium carbonate ($CaCO_3$) as high as 91.09 and as low as 49.35 per cent, and magnesium carbonate ($MgCO_3$) reaching 42.82 per cent, thus indicating that some of them consist almost entirely of dolomite. Iron pyrite was found as high as 3.27 per cent, and other constituents, as ferrous carbonate, ferric oxide, manganese carbonate and calcium phosphate occurred in small amounts.

The studies of Zalessky[1] in the Donetz Basin of Russia showed that the calcareous balls occurred there under conditions almost identical with those described for England and northern France. The coal seam and the shales carrying abundant concretions lay between two limestones and the same types of plant remains were preserved in much the same way.

" Niggerhead " coal. — In the Walsenburg district of Colorado and in the coal fields of Washington State and Alaska certain seams of coal have been intruded with igneous rocks and a great deal of natural coke occurs. In some of these seams most of the coal is made up of roughly spherical masses called " niggerheads," varying from an inch or less to a foot or more in diameter. They resemble somewhat the form taken by diabase or other basic rocks on disintegrating by spheroidal weathering. The laminations in the coal are still distinct in most of the balls, and in many of them portions of flat sides indicate the original joint cracks, but the corners are rounded off and some of the balls are almost spheres, (Fig. 77).

It might be thought that these bodies owe their form to a sort of concretionary development as a result of silicification or other form of mineralization of the coal when it was intruded by the igneous rock, but the following analyses show that it is not high in ash and it is considered a very good quality of coal in the Rocky Mountain fields.

[1] Zalessky, M. D., On the discovery of the calcareous concretions known as coal balls in one of the coal seams of the Carboniferous strata of the Donetz Basin. Bull. de l'académie Impériale des Sciences de St. Petersburg, VI Series, pp. 477–480, 1910.

The subspherical form is apparently due to the coal being heated to a high temperature with the driving off of certain volatile matter.

FIG. 76. — A sharp syncline near Hazelton, Pa., from which the anthracite has been removed by open-cut mining. (Photo by E. S. Moore.)

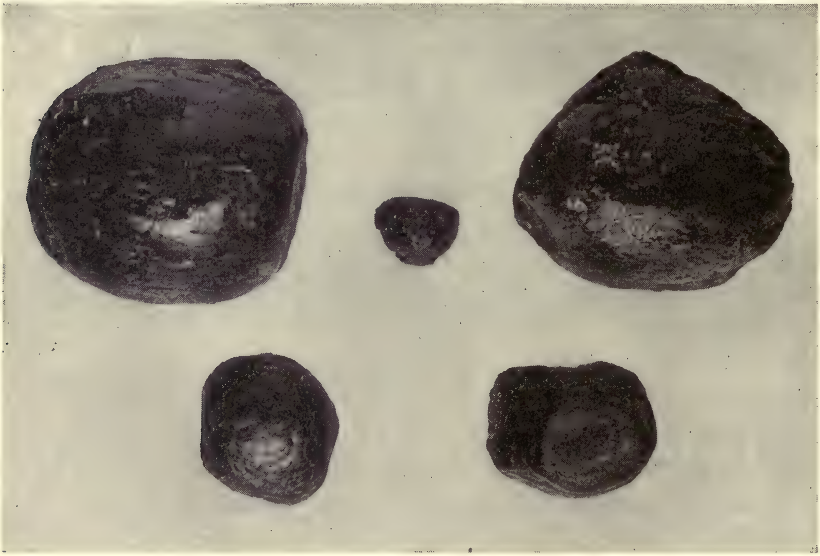


FIG. 77. — "Niggerhead" coal from Colorado.

It then contracted so that it scales off concentrically in the same manner as any other rock which has been heated and allowed to cool.

ANALYSES OF NIGGERHEAD COAL FROM COLORADO[1]

	I	II	III	IV
	Per cent	Per cent	Per cent	Per cent
Fixed carbon	53.09	55.20	51.51	54.81
Volatile matter	37.50	37.78	31.90	35.81
Moisture	2.06	2.22	....	2.63
Sulphur	.906	.714	.714	.742
Ash	7.35	4.80	9.85	6.75
Sp. gr.	1.308	1.300	1.324	1.312
B.t.u. (dry)	13,631	13,746	12,989	13,125

[1] Analyses furnished through kindness of D. A. Stout. From Huerfano County, Colorado. I, Cameron seam, II and III, Walsen seam and IV, Robinson seam.

There is also evidence in the smooth surfaces of the balls that considerable movement has occurred between them and the adjacent coal. This may have resulted from the great pressure exerted when the intrusion entered the coal seam and adjacent rocks and it probably aided in forming the rounded bodies. The spherical structure was apparently formed after the coal was jointed into blocks since remnants of the joint planes may still be seen in most of the balls. These joint fractures in all probability aided in the distribution of the heat from the igneous rocks and in the irregular cooling of the coal when the volcanic activity had subsided

The only other specimen of coal resembling these "niggerheads" from Colorado, which the writer has seen was found in a seam in the Newcastle district of Australia. That seam had also been intruded by igneous rock and a spherical mass found gave unmistakable evidence of having suffered from great pressure and some shearing. It was thought at the time to have been the result of pressure squeezing the more plastic coal around harder lumps of the vegetal matter in the seam, but it is probable that the heating of the coal may also have had an influence in producing the concretion-like body. A few specimens of these bodies have been reported from the Anthracite field of Pennsylvania apparently formed by pressure on the coal.

The nature of the origin of these peculiar bodies does not seem to be fully understood by mining men and more extensive observations regarding them are needed.

CHAPTER IX

PROSPECTING FOR COAL AND THE VALUATION OF COAL LANDS

Prospecting

Prospecting for coal may be considered as two operations. One of these is the search for coal in regions where it has not already been found and the other the testing of geological formations already known to contain at least some coal.

Searching for Coal in New Fields

Laws governing operations. — According to the laws of the United States, coal lands are classed as Mineral Lands and unoccupied coal lands may be obtained through the government departments. The legal conditions controlling the purchase of lands already occupied are quite different. The Land Office Regulations relating to entry on vacant coal lands in the Public Land States and Territories and the district of Alaska are as given below, (Secs. 2347 and 2348). These were issued April 12, 1907 and they abrogate all previous rules and regulations relating to coal lands,[1] (Sec. 2347).

Every person above the age of twenty-one years who is a citizen of the United States, or who has declared his intention to become such, or any association of persons severally qualified as above, shall, upon application to the register of the proper land office, have the right to enter by legal subdivisions, any quantity of vacant coal lands of the United States not otherwise appropriated or reserved by competent authority, not exceeding 160 acres to such individual person, or 320 acres to such association, upon payment to the receiver of not less than ten dollars per acre for such lands, where the same shall be situated more than 15 miles from any completed railroad (one constructed, equipped, and operating on date of entry), and not less than twenty

[1] Charles Shamel, Mining, mineral, and geological Law. Hill Pub. Co., 1907.

dollars per acre for such lands as shall be within 15 miles of such road. This statute was authorized March 3, 1873, and is still applicable. The lands which may be entered must be surveyed and legally subdivided, they must contain workable coal deposits, but they must not contain valuable deposits of gold, silver, or copper.

Coal lands may also be entered according to the following statute (Sec. 2348) on the basis of a preference right to purchase: Any person or association of persons severally qualified (as provided in Sec. 2347), who have opened and improved, or shall hereafter open and improve, any coal mine or mines upon the public lands and shall be in actual possession of the same, shall be entitled to a preference right of entry under the preceding section (Sec. 2347) of the mines so opened and improved: *Provided*, that when any association of not less than four persons severally qualified as above provided shall have expended not less than five thousand dollars in working and improving any such mine or mines, such association may enter not exceeding 640 acres, including such mining improvements. To preserve a preference right the person or association must present to the register of the proper land district, within sixty days from the date of actual possession and commencement of improvements a declaratory statement therefor, in all cases when the township plot has been filed.

An individual or the several individuals of an association are entitled to but a single entry on coal lands. No one can operate or work a coal mine for profit upon the public lands without having made the proper entry.

Those desiring information regarding public coal lands should apply to the register of a land district, who is furnished from time to time with schedules and maps. These maps show three types of lands: (1) Those lands known to lie outside of ascertained coal areas and open to entry under the general land laws. (2) Those lands known to contain workable deposits of coal, whereon prices will be fixed upon information derived from field examination. (3) Those lands containing coal of such character as may from their location with reference to transportation lines, be sold at the minimum price fixed by statute. The lands of the first and third types are entered at minimum prices as stated above and those of the second type at prices fixed in the schedules.

Entry on coal lands in Alaska: To make entry on unreserved coal lands in Alaska[1] the same individual and personal qualifications are necessary as in the United States but entry may be made on unsurveyed coal lands. In unsurveyed tracts the lands upon which a mine or mines are situated must be located in rectangular tracts of 40, 80, or 160 acres with north and south boundary lines run according to the true meridian and marked by permanent monuments. All locators shall within one year of making a location file a notice with the register of the land district.

To obtain a patent an application for such must be filed with the register and receiver of the land district within three years. A patent gives control of the land to the patentee and his heirs.

The regulations governing the control of coal deposits in lands other than the Public Lands of the United States vary with different states. In many states the person holding land in fee also holds the minerals lying beneath the surface unless they have been expressly reserved in the deed. In others, such as Wyoming and Colorado, the coal land is leased only on a royalty basis.

The recent leasing law for coal lands: On February 25, 1920, the President of the United States signed an act known as an "Act to promote the mining of coal, phosphate, oil, oil shale, gas and sodium on the public domain." This bill places the development of these lands, not including those of Alaska, under the control of the Secretary of the Interior and it throws open millions of acres of coal and oil lands in the West for leasing purposes. The law refers to lands classified or unclassified but it does not include: (*a*) Lands in National parks; (*b*) Lands controlled by the Appalachian Forest Reserve Act; (*c*) Lands in military or naval reservations; (*d*) Indian reservations; (*e*) Ceded or restored Indian lands the proceeds of which are credited to the Indians.

According to this act coal lands may be leased to citizens, associations of citizens, corporations, and municipalities in tracts of 40 acres or multiples thereof up to 2560 acres by one applicant. The tracts are to be contiguous if possible for them to be so. Railroads may work for their own use for railroad purposes only one grant for

[1] Regulations governing Coal Land Leases in the Territory of Alaska. Dept. of the Interior, Washington, May 18, 1916.

each 200 miles of road. There is to be paid to the Government a royalty on coal leases of not less than 5 cents a ton (2000 lbs.) and a yearly rental of not less than 25 cents an acre for the first year, not less than 50 cents an acre for the second to the fifth year inclusive, and not less than $1.00 an acre for the remainder of the term of the lease. Leases are for indeterminate periods not to exceed twenty years but renewable to a like extent. In an emergency individuals or associations may be allowed to mine coal for their own domestic use without payment of rent or royalty. This privilege is restricted to an area of 40 acres and a license of two years duration. Municipalities may lease coal lands for their own use without the payment of rent or royalty under the following special conditions: The coal must be used for domestic purposes only, which means household purposes; a municipality of less than 100,000 population is limited to an area not exceeding 320 acres, one of 100,000 to 150,000 population to an area not exceeding 1280 acres and one of a population of over 150,000 is limited to an area not exceeding 2560 acres. The special lease granting this privilege is limited to four years.

No person, association or corporation, except as provided, shall have more than one coal, phosphate or sodium lease during the life of such lease in any one state. "No person or corporation shall take or hold any interest or interests as a member of an association or associations or as a stockholder of a corporation or corporations holding a lease under the provisions of this bill which together with the area embraced in any direct holding of a lease under this Act or which together with any other interest or interests as a member of an association or associations or as a stockholder of a corporation or corporations holding a lease under the provisions hereof, for any kind of mineral leased hereunder, exceeds in the aggregate an amount equivalent to the maximum number of acres of the respective kinds of minerals allowed to any one lessee under this Act. Any interests held in violation of this Act are forfeited to the United States."

Permits, known as *coal prospecting permits* may be granted, which gives the holder the exclusive right to prospect unclaimed and undeveloped lands where exploratory work is necessary to determine the existence or workability of coal deposits. These permits cover a maximum area of 2560 acres and they are good for two years.

Criteria for Locating New Seams or Known Seams in New Areas

In looking for new seams of coal there are certain conditions which should govern the prospector's operations. A seam may outcrop at the surface but if the adjacent rocks have suffered much disintegration very little definite evidence of the coal may be found without excavating. There may often be found a black band, or area, known as the "smut" or "blossom" which indicates the position of the seam. In some cases the presence of a seam which is covered with clay or sand wash may only be inferred by finding minute fragments of the coal mixed with the sediment carried down grade by water or transported in a certain direction by a glacier. Outcrops are most frequently found in gullies and ravines and quite frequently seepages or springs of water in the bank indicate the position of seams of coal.

In prospecting it should be observed that coal is only found in stratified rocks, and it is absolutely useless to search for it in those of igneous origin. Further, of the stratified rocks, there are usually certain types which carry the coal. These are shales, or slates derived from the shales, and sandstones. Black shales are the most favorable. Although coal has been found in limestones, it is very rarely indeed that it is found in a limestone formation in which there is not also considerable shale or sandstone, and there is no chance of finding it in quantities in distinct limestone formations. Regarding sandstones and conglomerates, the latter rarely carry coal except along shaly and sandy bands. Clean sandstones are poor coal-bearers as most of the coal in sandy rocks is found in impure sandstone containing clay or in feldspathic sandstones known as arkoses.

Although shales and impure sandstones are favorable rocks for the occurrence of coal not all of them carry it. In America no coal has been found in rocks older than those of the Mississippian, or Lower Carboniferous series, but in Europe a little has been found in rocks as old as the Devonian. Carbonaceous shales may be found as low as the Archean rocks, but the geological and botanical conditions had not become favorable for the formation of coal before the periods mentioned above. There are many examples of people spending large sums of money in drilling in these older formations, as for ex-

ample, in the Ordovician black shales, where there is no possibility of finding coal. There is good evidence to show that the great groups of land plants which gave rise to the coal had not developed before the Devonian period, and in America as well as in some of the other continents the sea covered so much of the continent that there was little opportunity for coal to form in the Devonian.

The coal-bearing formations are found principally in the Carboniferous, Cretaceous, and Tertiary systems. There is a little coal in the Jurassic in Alaska, and outside of America the Jurassic and Triassic coals are important. In dividing these systems of rocks into smaller divisions so that certain seams of coal may be located or a seam may be traced from one basin to another the different plant fossils may be used to correlate beds, and animal fossils in the adjacent rocks often serve to identify the seams. Thiessen claims to have discovered from his microscopic studies that the plant spores found in any coal seam have characters distinct from those of spores in other seams, and may be used as a determinative factor in recognizing the seam in various localities. This new evidence of the difference in the spores from different seams is likely to be of considerable practical value in the future in correlating seams.

In addition to the fossils there are often other features which locally distinguish one seam from another, such as the presence of "sulphur balls" or other concretions in some seams and their absence in others, the fracture of the coal, the presence of streaks of cannel or mineral charcoal, the nature of the adjacent rocks and similar features. The adjacent rock may be a fire clay, a calcareous rock or some distinctive sandstone which can be recognized wherever met.

Testing coal-bearing formations to determine the extent of the seams. — A coal seam may vary greatly in thickness within very short distances or it may, like the Pittsburgh seam of the Appalachian province, extend with a fairly uniform thickness over several thousand square miles. Shallow seams may be tested with tunnels, pits, or shafts, but where they lie much below the surface prospecting is usually done with a core drill. The diamond drill is most commonly used, although a rotary calyx drill has also been employed. The advantage in using drills of this type is in the core which is obtained.

As few coal seams lie horizontally the length of the section of coal

in the drill core from any seam will depend upon the angle at which the hole perforates the seam and will vary inversely as the acute angle for a vertical hole. If the hole be vertical, the angle will be found by subtracting the angle of dip of the bed from 90°, that is, the angle will be the complement of the angle of dip. In case the hole is not vertical but is still in a plane normal to the strike, the angle which it makes with the seam can be found by subtracting the angle of dip from 90° and then adding the angle the hole makes with the vertical, if it be inclined in the opposite direction to the seam, or subtracting it, if it be inclined in the same direction. These figures may be easily obtained by use of a clinometer.

If the hole is driven so that it departs from the vertical in a plane which is parallel to the strike and therefore normal to the dip, the difference between the true thickness of the seam and the thickness shown in the core will increase as the angle which the hole makes with the vertical increases.

In the case of holes drilled at an angle to the vertical and lying in any other plane than the plane parallel to the direction of strike of the seam or in the plane normal to the strike, as mentioned above, the conditions become quite complicated and must be worked out for each individual case.

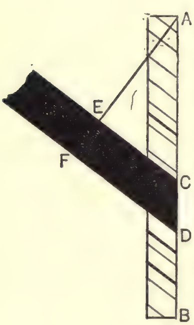


FIG. 78. — Graphic method of determining the thickness of a coal seam from the drill core.

In all the cases mentioned above, the true thickness of the seam may be determined from the thickness of coal in the core by a solution of the triangles involved, but the simplest method and one sufficiently accurate for all practical purposes is to solve the problem graphically. This is done as follows: In Figure 78 let AB be a drill core containing a band of coal CD. Carefully project the coal seam, keeping the proper inclination, and draw a line from A perpendicular to the projected seam. The distance EF will bear the same relation to the distance CD (which is already known) that the true thickness of the seam does to the thickness of the coal in the core since they are drawn to the same scale. If CD be 10 feet and EF scales half as much as CD the true thickness of the seam will therefore be 5 feet.

Determination of thickness of coal formations. — There are several means of determining the thickness of an outcropping coal seam or of a formation containing one or more seams, without the use of the drill. The method employed depends upon the circumstances. (1) If the beds lie flat and are exposed in a cliff (*a*) the vertical height of the cliff will be the thickness. (2) If the beds dip there may be several different conditions: the surface may be level where the formation outcrops (*b*); the rocks may outcrop in a slope, which is inclined in a direction opposite to the direction of the dip of the strata (*c*); the rocks may outcrop in a slope which is inclined in the same direction as the dip of the strata, (*d*) (Fig. 79). The thickness of the formation

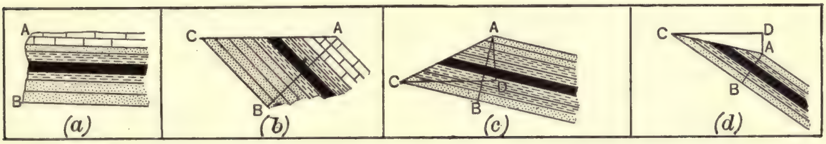


FIG. 79. — Determination of the thickness of a formation under varying conditions.

is found by solving the triangles in the three cases, (*b*), (*c*), and (*d*) as follows: (*b*) Since the angle of dip ACB and the distance CA may be measured, the distance AB is easily found from the formula. $\text{Sin } ACB = \frac{AB}{CA}$, or $AB = CA \text{ Sin } ACB$, (*c*) $AB = CA \text{ Sin } (ACD + DCB)$. The slope distance and angle of dip are measured and the angle of slope ACD may either be measured or found from its sine, computed from the length of the slope and the difference in elevation. (*d*) $AB = CA \sin (DCB - DCA)$.

As the angle of dip increases the horizontal distances normal to the strike approach more nearly the thickness of the formation until the dip becomes 90°, or vertical, and the two are then equal.

Graphic method: The thickness of a series may be very conveniently and rapidly determined by the graphic method when the angle of dip and the horizontal distance across the outcrop are known, (Fig. 80). In this diagram the numbers on the left hand side of the diagram represent various dip angles and each vertical space corresponds to any chosen unit of measurement. To determine the thickness find the number corresponding to the number of degrees in the dip angle and follow the horizontal line to the right for as many units as there are

in the distance across the outcrop. Then follow the curved line (or an imaginary curved line between two of the curved lines if the point falls between two lines) to the top of the figure and count the number of units between the point reached and the left margin. The vertical spaces may each be taken as equal to 5, 10, 20, 100, 1000, or any other number of feet, the same scale being used in all parts of the diagram

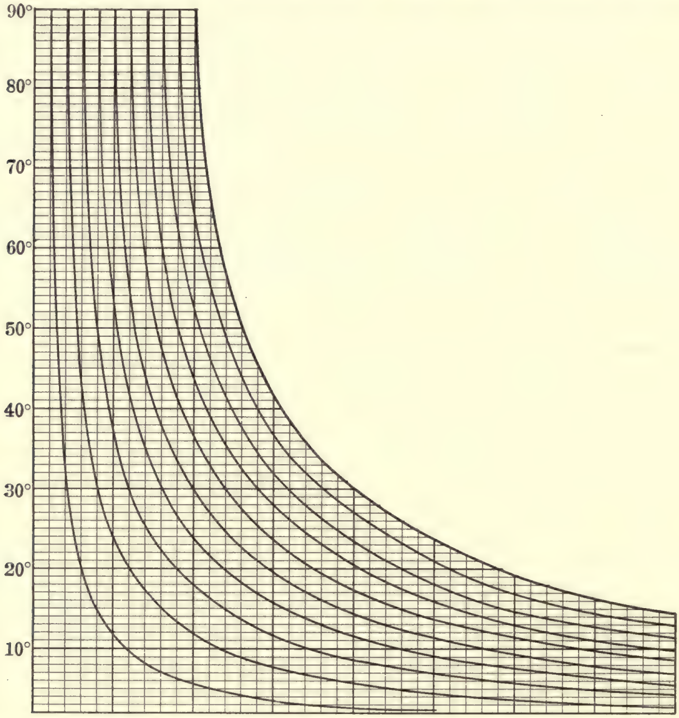


FIG. 80. — Diagram employed in the graphic determination of the thickness of geological formations. (After Hayes.)

in any one calculation. To illustrate its use: Let a formation outcropping on a level surface dip 30° and the distance across its outcrop normal to the strike be 1000 feet. Its thickness is found by following the horizontal line from 30° to the right and if each vertical space be considered equal to 100 feet, the point corresponding to 1000 feet will fall on the fifth curved line. If this line be followed to the top of the diagram and the same scale be used, it will be found that the distance to the left margin is 500 feet. Instead of considering each space

equivalent to 100 feet another scale might have been used, for example 200 feet or 50 feet per space. It is best in all cases to use as small a number of feet to a space as the diagram will permit in order to minimize the error in computing the thickness. In this connection it is sometimes wise to use a certain fraction of the distance across the outcrop to obtain the thickness of that fraction of the formation, and then to find the total thickness from this fraction. For example the total distance across the outcrop of the formation is 2000 feet. In order to use a large scale on the diagram find the thickness corresponding to a distance of 200 feet and multiply this by 10, to find the thickness for the whole formation.

In addition to the methods suggested above, the thickness of a formation may be determined graphically by simply drawing to scale diagrams like those in Figure 79, and scaling off the distance representing the thickness. If this is done carefully and on a fairly large scale the results will be satisfactory for most purposes since in most cases thicknesses and dips are subject to considerable variation within short distances.

Determination of the depth of a coal seam at different points. — If an outcropping seam lies flat its depth below the surface at any point can readily be found from the topographic map. On many geological maps structural contour lines are drawn on one important seam in a coal-bearing formation and all points on any one of these lines have the same elevation above sea level. These contours bring out the subterranean topography and the structural features of the seam and when they are placed on a topographic map the depth of the seam at any point is quickly found by taking the difference between the elevation of the surface at that point as shown on the topographic map and the contour line on the seam lying beneath this point, (Fig. 81).

When an outcropping seam dips it may be desired to find its depth at certain points at various distances, and in various directions from some point on the outcrop. For convenience in discussion, the depth of a seam in three directions from a point on the outcrop and at varying distances from that point will be considered. The conditions are illustrated by Fig. 82. Let $ABCD$ represent a section of a seam outcropping along AB. The direction of strike is parallel to AB and the direction of dip normal to AB and parallel to PM.

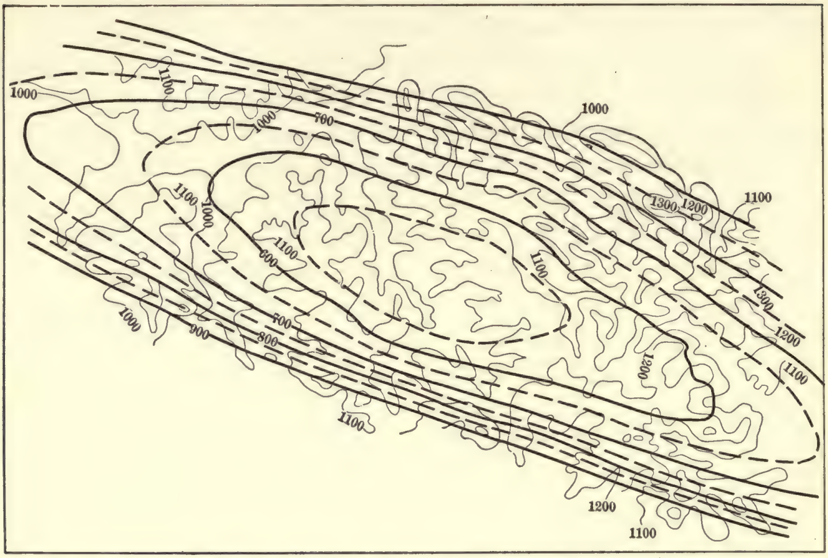


FIG. 81. — Relation between surface contours and structural contours drawn on the surface of a coal seam underground. The former are the light lines and the latter the heavy ones.

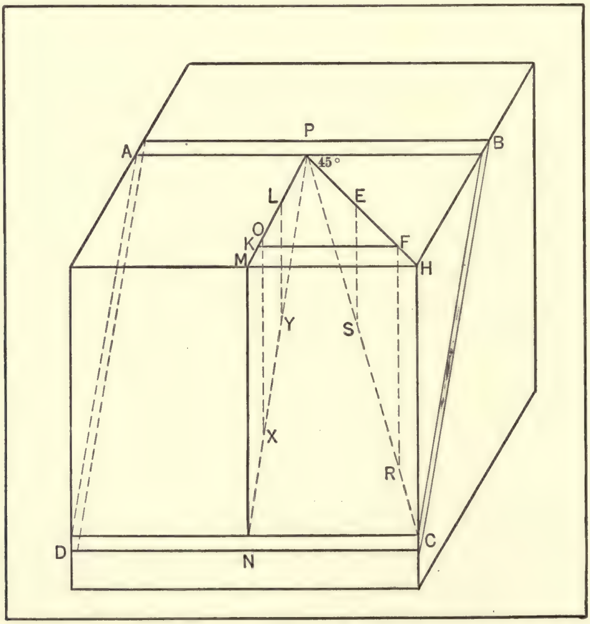


FIG. 82. — Diagram illustrating the determination of the depth of a coal seam at varying distances and in different directions from a point on the outcrop.

(1) In the first case consider the depth of the seam below various points *L*, *O*, and *M*, along a line parallel to the dip. The angle of dip, *MPN* and the distances *PL*, *PO*, or *PM* being measured, the depth is found from the tangent of the angle of dip. It is seen that the depth at any point will be directly proportional to the distance from the point *P*, and the following table shows the depth of a seam at points 10 feet from a point on the outcrop when measured on a horizontal surface, supposing the seam dips at various angles from 5° to 85°. At 90° the bed is vertical. To find the depth of the seam beneath any other point along this line multiply the number given in the table by the distance in feet and divide the result by 10.

TABLE SHOWING THE DEPTH OF A COAL SEAM AT VARIOUS DISTANCES IN DIRECTION OF DIP FROM THE OUTCROP, FOR DIFFERENT ANGLES OF DIP

Angle of dip	10 feet from outcrop	Angle of dip	10 feet from outcrop
5°	.8749 feet	50°	11.918 feet
10	1.7633	55	14.281
15	2.6795	60	17.321
20	3.6397	65	21.445
25	4.6631	70	27.475
30	5.7735	75	37.321
35	7.0021	80	56.713
40	8.3910	85	114.300
45	10.0000		

(2) In the second case consider the depth at various points along a line 45° from the direction of dip. Or in the diagram (Fig. 82) let the direction of the dip be south, the strike east and west, and the direction (*PH*) under consideration, southeast. On this line, *PH* the depth at any points such as *E*, *F*, and *H*, will be found by first measuring the distance *PE*, *PF*, or *PH*, then drawing a line from this point normal to the line *PM* meeting *PM* at the point *K*. The triangle *PFK* thus formed is solved, *PK* is found and the problem then becomes the same as that described above for the first case considered. The following table shows the depth of a seam at points 10 feet from a point on the outcrop, measured for various dips of 5°–85° in a direction 45° from the direction of dip.

To obtain the figures for any other point, multiply by the distance in feet and divide by 10.

TABLE SHOWING DEPTH OF A SEAM AT POINTS ALONG A LINE 45° FROM DIRECTION OF DIP FOR VARIOUS ANGLES OF DIP

Angle of dip	10 feet from outcrop	Angle of dip	10 feet from outcrop
5°	.61855 feet	50°	8.42602 feet
10	1.24665	55	10.09666
15	1.89440	60	12.24594
20	2.57326	65	15.16161
25	3.29681	70	19.42482
30	4.08176	75	26.38594
35	4.95048	80	40.09609
40	5.93243	85	80.81010
45	7.07110		

The formula for determining the depth D at a point C feet from the outcrop and in a direction at $A°$ to the direction ot dip, if the angle of dip be $B°$, is

$$D = \text{Tan.}\ B \times C \cos A.$$

An instrument known as *Brunton's slope chart* is a convenient apparatus for determining the apparent dip of the bed at any angle of divergence from the true dip. It is for the purpose of mechanically solving the formula $\text{Tan}\, C° = \text{Sin}\, A° \,\text{Tan}\, B°$, where A is the angle of divergence from the true dip, B the true dip, and C the apparent dip. Thus, after the angle C has been found, the depth at any point is found just as in the case where the measurement is taken along the true dip by finding the tangent of C and using the table given for the first case.

(3) In the third case it should be observed that any point along the line of strike of a coal seam will be at the same depth as every other point on that line whether the seam be considered at the surface or at the bottom of a mine shaft. This is evident since the strike is the line along which the seam intersects a horizontal plane.

The Valuation of Coal Lands

Factors governing the value. — The chief factors which influence the value of coal lands are: (*a*) the proximity of the coal to an important market center; (*b*) the transportation facilities; (*c*) the abundance or scarcity of coal in the district; (*d*) the nature of the coal; (*e*) the depth at which it occurs; (*f*) the thickness of the seam; and (*g*) the

other geological conditions which affect mining operations, such as folded or faulted strata, abundance of water and the character of the floor and roof of the seam. The nearness of coal deposits to a good market may be offset by labor difficulties and poor quality of the coal or the difficulty of mining it, while the handicap of being a considerable distance from the market may be overcome by good transportation facilities, especially by water, and the favorable condition of most of the other factors mentioned. If there be little fuel in the vicinity of a large city the lower grades of coal, such as lignite, may bring a good price whereas they would scarcely be used if there were plenty of good bituminous coal or anthracite in the region. Good gas coal is in demand, especially around cities, and high-grade coking coal is much sought after for metallurgical purposes. If it occurs in large amounts, industrial centers may grow up in areas where it is found.

THE MAXIMUM DEPTH OF COAL MINES

The depth of coal mine shafts in the United States. — In the United States it is customary to regard any coal lying below 3000 feet as negligible in estimating the value of the land, because industrial conditions make it impossible at present to mine the coal profitably at a greater depth. It is the consensus of opinion, however, that the time is not far distant when the maximum depth for profitable mining will be extended to at least 4000 feet, as this depth is almost attained in Belgium at the present time, and in England for almost half a century all seams less than 4000 feet deep have been figured in the reserves. There are no mechanical impediments to mining at that depth or even at a much greater depth; but the abundance of coal, the high cost of labor and the low price which usually prevails in the United States when compared with prices in those countries where deep mining is carried on make it impossible to mine coal profitably at these great depths in this country.

The maximum depths at which coal is mined at the present time in the various fields of this country are approximately as follows:[1] The deepest mining is in the anthracite region of Pennsylvania, and it reaches about 2200 feet although the deepest shaft is only 1850 feet.

[1] Fisher, C. A., Depth and minimum thickness of coal beds as limiting factors in valuation of coal lands. U. S. Geol. Survey, Bull. 424, p. 48, 1910.

This depth does not indicate the maximum depth of the coal in the anthracite region as the depth of a few of the basins has not yet been determined and from every indication it is very great. In the not far distant future it is probable that coal will be mined from the Southern Field at a depth of at least 3500 feet. In the Schuylkill section the coal probably reaches 4500 feet or more in depth.

In the bituminous fields of the Appalachian province the coal does not lie at great depths in many places, the deepest so far known being in Alabama where some of it exceeds 3000 feet. The deepest shafts are not over 1000 feet in the states of Pennsylvania, Ohio, West Virginia, eastern Kentucky, Tennessee, and Alabama, and there are large areas where all shafts are less than 200 feet in depth.

In the Eastern Interior field, including Illinois, Indiana, and western Kentucky, the greatest depth reached is at a mine in Illinois, which is slightly over 1000 feet, but most of the coal in these states is comparatively shallow. In Michigan the seams lie very close to the surface and the shafts are seldom, if ever, more than 200 feet deep.

In the Western Interior field the depth reached in Iowa, Missouri, and northeastern Kansas scarcely exceeds 300 feet, while in eastern Kansas, Oklahoma, and western Arkansas the depth is considerably greater. A test shaft 1170 feet deep was sunk near Atchison, Kansas, but it has not been regularly operated. With the exception of this one the deepest shaft is about 800 feet and is found in the McAlester district of Oklahoma. In Arkansas the deepest shaft is about 500 feet and in Texas the shafts are comparatively shallow.

In the northern Great Plains province mining has not been carried beyond about 500 feet. A shaft 480 feet deep has been reported from the Judith Basin region and there are some less than 400 feet near Sheridan, in the Fort Union region. In the Black Hills region the maximum depth is not over 400 feet and in the Assinniboine region of northern Montana not over 300 feet.

In the Rocky Mountain province, owing to more intense folding and faulting, the depth of the mines is considerably greater than in the Great Plains or the Interior province. In Wyoming, at Rock Springs, there is a shaft about 2000 feet deep and in the Hams Fork region there is one which is reported to be over 1600 feet. At Cokedale, Montana, a mine was worked at a depth of 1300 feet and near Carbondale, Colorado, the Spring Gulch mine is down about 1500

feet. In southern Colorado and northern New Mexico there are some mines working at a depth of over 1100 feet, and in the vicinity of Glenwood Springs, and at Canon City, Colorado, shafts are about 1000 feet deep. Elsewhere in the Rocky Mountain province the mines are generally less than 600 feet deep. In the Pacific Coast province the deepest mines are found in Washington. The Roslyn mine is said to be over 700 feet deep. In the Coos Bay field of Oregon the coals lie under 500 feet of strata and in central California the depth is about 300 feet.

The maximum depth of coal mines in foreign countries. — The deepest shaft in the world is in Belgium and the latest figures available give its depth as 3937 feet. Other mines in the Mons district of that country run from 2500 to over 3000 feet. The average throughout Belgium is placed at 1444 feet by E. Lozé.

In England the Rams mine at Manchester is not far short of the depth of the Belgian shaft, being over 3480 feet; a seam 2 to 6 feet in thickness is worked at this mine. In the same district there are two other mines each over 3300 feet in depth, but these are not classed as shafts. A number of mines in other fields run from 2000 feet to over 3000 feet. In South Wales the Ocean Collieries reach 2700 feet.[1] In Scotland the deepest workings are near Edinburgh and they are down to 2700 feet. The deepest shaft in Great Britain is said to be 2820 feet, but some of the collieries mentioned above are considerably deeper than this shaft. In France some mines reach 3000 feet and in Germany mining has been carried to over 3100 feet. In the Rhenish-Westphalian district the average depth of the mines is said to be about 1700 feet.

Australia has a shaft 2937 feet deep near Sydney Harbor, New South Wales. This shaft was sunk to a 3-foot bed of coal which outcrops at Newcastle and dips southward towards Sydney.

The Minimum Thickness of Coal Seams Mined

There are several factors which govern the minimum thickness at which coal seams may be worked. The most important of these factors are: the market for, and the character of, the coal; the nature of the enclosing rocks; the association of a thin seam with other seams; the depth of the seam; and the training of the miners.

[1] Report of the Royal Commission on Coal Supplies, 1871 and 1901–1905.

So far, much thinner beds are worked in some foreign countries than in the United States. The cost of mining thin seams usually increases rapidly as most miners demand a bonus or refuse to work the seam if it be less than a certain thickness. A mine manager in New Zealand stated that the labor conditions there prohibit the working of any seam less than 4 feet thick and the contract price for mining at one mine visited by the writer was 2 shillings 8 pence for a seam 4 feet to 4 feet 6 inches thick down to 2 shillings 4 pence for a seam 5 feet thick or over, showing a decrease in cost of mining of 4 pence per ton for an increase in thickness of 6 inches or more.

Thin seams mined in the United States. — Owing to the high quality of certain thin seams of coal or their chance location near a large city or important industrial center, the working of them is not confined to any particular part of the country. The following table compiled from the work by Fisher[1] shows the thickness of the thinnest seams reported as worked in the various states.

TABLE SHOWING THE THICKNESS OF THIN COAL SEAMS WORKED IN VARIOUS STATES

State	Thickness of Seam	
Alabama	22–24 inches.	
Arkansas	14 inches.	From a stripping.
Colorado		
Anthracite	18–42 inches.	From a drift.
Bituminous	18–84 inches.	From a drift.
Illinois	20 inches.	From a slope.
Illinois	17 inches.	From a drift.
Indiana	22 inches.	
Iowa	14–18 inches.	From a shaft 230 feet.
Kansas	15–18 inches.	From a shaft.
Kentucky	24 inches.	
Maryland	30 inches.	
Michigan	24 inches.	
Missouri	12 inches.	From a shaft 44 feet.
Missouri	12 inches.	From a drift.
Montana	30 inches.	
New Mexico	7–15 inches.	
Ohio	26 inches.	
Oklahoma	22 inches.	
Pennsylvania		
Anthracite field	18 inches.	
Western Clearfield district	17–48 inches.	
Tennessee	22 inches.	
Texas	19 inches.	From a shaft.
West Virginia	20–24 and 24–36 inches.	
Wyoming	16 inches.	

[1] Op. cit., p. 69.

Many of the thin seams in this table are mined for local use and nearly all of them are comparatively shallow. Some are from drifts and some from strippings, so that on the whole their thickness is rather below a good minimum for ordinary mining operations, although the official regulations governing coal lands of the United States place the minimum limit of thickness for a workable seam at 14 inches.

Thin seams mined in other countries. — Some very thin seams of coal of special quality have been worked in foreign countries. A bed of cannel 8 inches thick has been mined in Lancashire, England, and this probably represents the thinnest seam on record. Many beds ranging from 10 inches to 20 inches and consisting of various types of bituminous coal have been mined in different parts of England and Wales, while in Scotland beds ranging from 15 inches upward in thickness have been worked.

In Belgium several seams not more than 11 inches thick have been worked, and other seams 13–15 inches thick are regularly mined where the coal is of high grade.

Estimation of the Value of Coal Land per Foot-acre

The price of coal at the mine and the cost of mining. — The value of an acre of coal land in the United States before the war varied all the way from $10 to $2000. The latter figure is that stated by Ashley[1] for some of the land in the Connellsville district of Pennsylvania. There are, however, some areas which are held at a much higher figure than this.

In attempting to arrive at the value of the coal in the ground the price per ton at the mine and the possible fluctuations in price are taken as a basis. The figures given below represent the price of coal at the mine in various states for the years 1912, 1913, and 1914[2] and they may be taken as an indication of the prevailing prices in different parts of the country although it must be remembered that the price varies with the demand, and the location will have a great influence upon the local price. For example, small outputs of coal have sold as high as $4.10 per ton at the mine in Idaho even in normal

[1] Ashley, G. H., The valuation of public coal lands. U. S. Geol. Survey, Bull. 424, 1910.

[2] Mineral Resources, U. S. Geol. Survey, 1914.

years, and recently during a period of scarcity reports have been received of coal selling for $10.00 and $11.00 a ton at some mines in Pennsylvania.

TABLE SHOWING THE AVERAGE PRICE PER SHORT TON AT THE MINE

State	1912	1913	1914
Alabama	$1.29	$1.31	$1.34
Arkansas	1.71	1.76	1.72
California	*a*2.33	*a*3.54	*b*2.85
Colorado	1.49	1.52	1.66
Georgia	1.49	1.41	1.44
Illinois	1.17	1.14	1.12
Indiana	1.14	1.11	1.10
Iowa	1.80	1.79	1.79
Kansas	1.62	1.67	1.64
Kentucky	1.02	1.05	1.02
Maryland	1.18	1.24	1.27
Michigan	1.99	1.99	1.99
Missouri	1.76	1.73	1.73
Montana	1.82	1.74	1.75
New Mexico	1.42	1.46	1.61
North Dakota	1.53	1.52	1.52
Ohio	1.07	1.10	1.13
Oklahoma	2.14	2.05	2.06
Oregon	2.60	2.53	2.78
Pennsylvania — Bituminous	1.05	1.11	1.07
Anthracite	2.11	2.13	2.07
South Dakota	....	1.96	1.93
Tennessee	1.14	1.14	1.14
Texas	1.67	1.77	1.69
Utah	1.67	1.65	1.59
Virginia	0.96	1.01	1.01
Washington	2.39	2.38	2.20
West Virginia	0.94	1.01	0.99
Wyoming	1.58	1.56	1.55
Average Bituminous	1.15	1.18	1.17
Average Anthracite of Pennsylvania	2.11	2.13	2.07

a Includes Alaska.
b Includes Idaho and Nevada.

After a consideration of many fields Findlay[1] concludes that the cost of mining bituminous coal, including operating and related expenses amounts on the average to about 90 per cent of the sale price. The average cost per short ton to the Pittsburgh Coal Company from a large number of mines for five years was 89 cents and to the Monongahela River Consolidated Coal and Coke Company for nine years, 91 cents.

[1] J. R. Findlay, The cost of mining, Eng. and Min. Jour., Vol. 87, p. 948, 1909.

In Pennsylvania, the cost of mining anthracite is considerably higher than that of mining bituminous coal. The following figures show the cost per long ton to three large companies in 1905.[1]

The Delaware, Lackawanna and Western	$1.80
The Delaware and Hudson	2.09
The Lehigh Coal and Navigation Company	2.02

Between the years 1902 and 1908 the costs to the Philadelphia and Reading Coal and Iron Company varied from $1.85 to $2.00 per short ton.

The reports published by the committee of the Federal Trade Commission[2] show the following figures for the cost of producing coal in the several states mentioned, during recent years.

PENNSYLVANIA ANTHRACITE; AVERAGE COST PER GROSS TON

	Labor	Supplies	General Expenses	Total Cost f.o.b. mine
1913–1918, inclusive	$1.58–3.31	$0.29–0.80	$0.33–0.61	$2.59–5.11

AVERAGE COST PER NET TON OF BITUMINOUS COAL.

Labor	Supplies	Total cost f.o.b. mine	Margin realized
Pennsylvania	S. W. field.		
1916 $0.82	$0.12	$1.19	$0.17
1917–18 $0.88–1.38	$0.17–0.27	$1.35–$1.94	$0.55–1.40
	Central field		
1916 $0.92	$0.10	$1.32	$0.08
1917–18 $1.12–1.73	$0.15–0.31	$1.62–2.38	$0.64–1.10
Illinois, 5 districts.			
1916 $0.74–1.48	$0.05–0.16	$0.94–1.84	$0.03–0.12
1917–18 $0.83–2.26	$0.07–0.32	$1.05–2.85	$0.20–0.80
Ohio, 8 districts.			
1916 $0.78–1.19	....	$1.00–1.44	
1917 $0.98–1.65	....	$1.35–2.21	$0.54–1.03
1918 $1.25–2.24	....	$1.73–2.96	
Indiana, 2 districts.			
1916 $0.87–1.52	....	$1.09–1.99	
1917 $1.08–1.73	....	$1.37–2.16	$0.45–0.51
1918 $1.42–2.25	....	$1.85–2.77	
Michigan.			
1916 $1.58	....	$2.08	
1917 $1.95	....	$2.55	$0.65
1918 $2.52	....	$3.38	
Alabama, 3 districts.			
1918 $1.53–2.00	....	$2.17–2.38	
Tennessee, 3 districts.			
1918 $1.30–2.14	....	$1.77–2.84	
Kentucky, 4 districts.			
1918 $1.25–1.61	....	$1.74–2.28	

[1] Chance, H. M., The cost of mining coal, Eng. and Min. Jour., Vol. 87, p. 1099, 1909.
[2] Reports of the Federal Trade Commission on Coal, June 30, 1919.

The general expense increased gradually during the six years, but the lowest labor cost as well as the lowest total cost was in the period April to August, 1915.

The margin realized on the mining operations from 1913–1918 was as follows: 1913, $0.31–0.44; 1914, $0.22–0.50; 1915, $0.90–0.50; 1916, $0.38–0.57; 1917, $0.54–0.72; 1918, $0.35–0.39.

Weight of coal in a foot-acre. — The amount of coal under a given area is estimated by the foot-acre and it is directly related to the specific gravity of a solid mass of the coal. A cubic foot of water weighs 62.5 pounds. A cubic foot of coal with a specific gravity of 1.3, a good average for bituminous coal, will, therefore, weigh 81.25 pounds. This gives 24.6 cubic feet per short ton and 27.5 cubic feet for a long ton of 2240 pounds. It is often assumed that 0.9 cubic yard of bituminous coal equals one ton. This is equivalent to 24.3 cubic feet per short ton and corresponds very well with the figure given above. Good Pennsylvania anthracite will weigh in the block about 92 pounds and in lump 57 pounds to the cubic foot.

An acre contains 43,560 square feet and a foot-acre that number of cubic feet. This would yield about 1770 short tons providing it could all be extracted in mining. The percentage recoverable in mining will vary greatly according to conditions, such as the thickness of the seam, its freedom from partings and irregularities, the condition of the roof and other things, such for example as location beneath a town or city. Some companies under favorable conditions recover 97 to 98 per cent of the coal while others do not take out more than 50 per cent or about 880 tons per foot-acre. A fair average might be 80 per cent recovered, which gives about 1400 tons per foot-acre. A 5-foot seam would therefore yield on this basis about 7000 tons per acre. It should be borne in mind that it may be impossible to mine, by present methods, more than a small portion of a bed which is more than 30 feet thick, and an allowance must be made for this difficulty.

Estimate of coal in seams of varying thickness. — It almost invariably happens that when a geologist examines a coal property he must estimate the coal in a number of seams of varying thickness lying one above another. The best procedure is first to secure a map of the property outlined on cross-section paper, and then proceed to divide the property into areas beneath each of which the average

thickness of the coal is estimated, from all the available data, to be a certain figure. The whole property is divided up in this way, and the sum of the tonnages computed for the various areas will give the total tonnage for the property. The larger the number of areas into which the property is divided, the greater the probability of securing an accurate estimate, in most cases. The seams may be lettered or numbered and then treated separately in dividing the property into the various areas.

Royalties paid on leases. — The royalty paid on coal lands varies greatly in different fields. The variation is very much greater than in the price of coal at the mine in the different fields, and the difference in royalty demanded does not always correspond to the difference in the price per acre, which might be demanded for land in different areas. This is because the rate at which the coal is mined has an important bearing on the relative income from the royalty and that from the sale of the land, since the interest on the money and the taxes amount to a considerable item if the time required for mining the coal be long. According to Ashley[1] the royalties paid in the Anthracite region of Pennsylvania previous to 1910 ran up to 50 cents or locally to $1.00 a ton, and the writer has obtained similar figures for this field in more recent years, with some running as high as $1.40 a ton. In the bituminous fields of the state the royalties varied from 5 to 30 cents except in a few cases in which they went up to $1.00 or more in the Connellsville field. The average for the state was perhaps 10 cents a ton. In Ohio the royalty varied from 8 cents to 15 cents. In Illinois 2 cents to 25 cents has been paid, and in Indiana 2 cents to 10 cents. The West Virginia royalties which have been reported run from 8 to 24 cents, the latter in the coke regions. In Kentucky, Tennessee and Alabama the figures are from 3 cents to 12½ cents and in Arkansas and Oklahoma 3 to 8 cents. In Colorado, state lands pay 10 cents and other lands from 8 to 27 cents. On account of the great local demand for coal in limited areas in Wyoming some royalties have been reported as high as $1.00 a ton, but they usually run from 3 to 10 cents. Montana royalties are about 15 cents so far as known, and in Utah some local mines have paid as high as 75 cents. All these figures have changed rapidly during the last few years of inflated prices.

[1] Op. cit., pp. 9 and 10.

In many of the fields where the royalties mentioned above are paid there is also a bonus and in most cases a minimum yearly royalty is demanded in the contract. In some states the royalty decreases as the output increases and in Kentucky it fluctuates with the thickness of the seam.

Classification and Valuation of Coal Lands by the United States Government

The "Regulations on the Classification and Valuation of Coal Lands," adopted by the Secretary of the Interior on April 10, 1909, contain the following clauses:

I. For purposes of classification and valuation, coal deposits shall be divided into four classes.

A, Anthracite, semianthracite, coking and blacksmithing coals.

B, High-grade bituminous, non-coking coals having a fuel value of not less than 12,000 B.t.u. on an unweathered, air-dried sample.

C, Bituminous coals having a fuel value of less than 12,000 B.t.u. on an unweathered, air-dried sample, and high-grade subbituminous coals having a fuel value of more than 9500 B.t.u. on an unweathered, air-dried sample.

D, Low-grade subbituminous coals having a fuel value below 9500 B.t.u. on an unweathered, air-dried sample, and all lignite coals.

II. Lands underlain by coal beds, none of which contain 14 inches or over of coal, exclusive of partings, of Class *A*, *B*, or *C*, or over 36 inches of Class *D*, shall be classified as non-coal land.

III. Lands containing coals of classes *A* and *B* of any thickness at depths greater than 3000 feet shall be classified as non-coal lands, except where the rocks are practically horizontal and the coal lies within 2 miles of the outcrop or point at which it can be reached by a 3000-foot shaft.

IV. Lands containing coals of class *C* of any thickness at a depth greater than 2000 feet shall be classed as non-coal lands, except where the rocks are practically horizontal and the coal lies within 2 miles of the outcrop or point at which it can be reached by a 2000-foot shaft.

V. Lands containing coals of Class *D* of any thickness at a depth greater than 500 feet shall be classed as non-coal lands, except where the rocks are practically horizontal and the coal lies within 1 mile of the outcrop or point at which it can be reached by a 500-foot shaft.

VI. The prices of coal lands of Classes *A*, *B*, and *C* shall be determined on the basis of estimated tonnage at the rate of one-half cent to 1 cent per estimated ton for Class *C*, 1 to 2 cents per estimated ton for Class *B*, 2 to 3 cents per estimated ton for Class *A*, when the lands are within 15 miles of a completed railroad and half that much when at a greater distance; but the price shall in no case exceed $300 per acre, except in districts which contain large coal mines where the character and extent of the coal are well known to the purchaser. When, however, topographic conditions affect the accessibility of the coal the land within the 15-mile limit may be given a lower valuation, but in no case shall it be placed at less than the minimum, and a graded allowance may be made for increasing depth, with the same restriction.

VII. The rates per ton in the preceding paragraph are based on the assumption that only one bed is present. If more than one bed occurs in any tract of land in such relationship that the mining of one will not necessarily disturb the other, then for the second bed there shall be added to the price of the first bed 60 per cent of the value of the second bed according to the schedule, 40 per cent of the value of the third bed, and 30 per cent of the value of each additional bed; but the estimated price for coal shall in no case exceed $300 per acre, except in districts which contain large coal mines where the character and extent of the coal deposits are well known to the purchaser. Where a bed is over 15 feet thick, the normal value shall be placed only on 15 feet; the next 15 feet or part thereof shall be valued at 60 per cent of the normal; the next 15 feet or part thereof at 40 per cent of the normal and the rest of the bed at 30 per cent of the normal.

VIII. The tonnage shall be estimated for the purpose of valuation on the basis of 1000 tons recovery per acre-foot.

IX. The price of lands of Class *D* shall be the minimum provided by law, $20 per acre when within 15 miles of a railroad and $10 per acre when at a greater distance.

X. In all valuations of coal lands any special conditions enhancing the value of the land for coal-mining purposes shall be taken into consideration.

XI. When only a part of a smallest legal subdivision is underlain by coal the price per acre shall be fixed by dividing the total estimated coal values by the number of acres in the subdivision, but in no case shall this be less than the minimum provided by law.

XII. When lands which were at the time of classification more than 15 miles from a railroad are brought within the 15-mile limit by the beginning of operation of a new road all values given in the original classification shall be doubled by the register and receiver.

XIII. Except in case of entries now pending or entries made prior to classification, review of classification or valuation may be had only upon application therefor to the Secretary accompanied by a showing clearly and specifically setting forth conditions not existing or known at time of examination.[1]

In formulating these regulations it was desired that the price should be such that it would discourage private citizens from buying coal lands for speculation with a view to holding them for future favorable conditions, but at the same time that it should not retard the business of legitimate coal mining. The royalty rate taken as a rough standard in figuring the price per ton was 10 cents, since it was believed to be a fair average for the whole country. On the adoption of the above regulations much land was withdrawn from entry in order that it should be classified and valued by the Geological Survey. The amount of land withdrawn from coal entry on November 1 of that year in the nine states, Wyoming, Washington, Utah, Oregon, Montana, New Mexico, Colorado, South Dakota, and North Dakota, amounted to 31,872,171 acres. The area withdrawn from all entry in the same states on that date was 11,862,576 acres, and the amount of classified land restored to entry was 35,915,255 acres.

[1] Ashley, Op. cit., pp. 37 and 42.

There has been a growing feeling among government officials and others interested in coal lands that the public coal lands should be leased for the purpose of mining only and the title to the land should rest with the State.[1] Colorado has had for many years a leasing system on a royalty basis of 10 cents a short ton run-of-mine, less one-twelfth of the minimum annual royalty which shall have been paid at the beginning of the year. This minimum royalty is paid whether any coal is mined or not. Wyoming also adopted the leasing system in 1907 and in that state an " advance royalty " is paid and is applied on a royalty of 6 cents on all coal mined, and sold up to 25,000 tons, 5 cents if amount is between 25,000 and 50,000 tons, 4 cents if it falls between 50,000 and 100,000, and 3 cents if it exceeds 100,000 tons per annum. The lessee must spend not less than $200 on development work. As indicated above, Congress has also recently passed a leasing bill which permits the leasing of public coal lands from the Government.

[1] Bain, H. F., Leasing the Federal Coal Lands, Min. and Sci. Press, Vol. 96, p. 73, 1908. The value of Coal Land. Mines and Minerals, Vol. 29, p. 366.

CHAPTER X

MINING OF COAL

Introduction

The process or mining coal has become a highly developed art and a detailed description of all methods employed would embrace a very extensive literature. In this chapter only the main methods employed are described and reference is made to a few of the larger works in which the details of the various operations are found.[1] With the introduction of labor-saving machinery, resulting especially from the more extensive use of electricity in mines, rapid changes in methods are taking place and before long the bulk of all coal mined under favorable conditions, in the more advanced countries will be cut, broken and loaded by machinery. The development of large steam shovels has made it possible to strip many coal seams formerly out of reach in open pit mining and to mine them on the surface, while the working out of the thicker seams underground necessitates the mining of thinner seams. In this work the use of mechanical conveyors and other labor-saving devices is becoming more common.

Mining Methods

The main methods employed in coal mining may be classed as (1) *Open work* and (2) *Underground*, or *closed work*. The first is frequently known as *stripping* or *open-pit* mining. The underground methods may be divided into *Room-and-pillar* and *Longwall* methods, and there are several modifications of each of these.

Stripping Method

In areas where a good seam of coal underlies a thin overburden it pays to strip off the covering. The depth to which this stripping may be profitably carried depends upon many factors. It has been

[1] Coal miner's pocketbook, McGraw Hill, 1916. Peele's Handbook for mining engineers, John Wiley & Sons, Inc., 1918. Practical coal mining by W. S. Boulton, London, 1907. Vols. 1–6. Colliery working and management, Bulman and Redmayne, 1912.

considered in the past that a foot of overburden could be removed by hand for each foot of coal obtained. Most stripping is done at the present day, however, by the large steam shovel of ordinary type, the rotary shovel or the dragline excavator. In Illinois hydraulic means are employed to some extent in stripping. The proportion of overburden to coal which may be profitably removed has therefore increased to from 3 to 6 times the figure stated. The proportion will vary greatly according to the grade and the price of the coal and the nature of the overlying rock. A heavy, little-jointed sandstone or limestone which requires blasting, or a loose rock which is full of water and runs readily may increase to a large degree the relative cost of stripping.

Fig. 83. — Stripping on the Mammoth Seam near Hazleton, Pa. (Photo by E. S. Moore.)

In the anthracite region of Pennsylvania extensive stripping operations are carried on, especially in the district around Hazleton where the Mammoth seam is thick, (Figs. 76 and 83). In some places this seam runs from 50 feet up to 100 feet or more, where it is duplicated by folding, and an overburden up to 90 feet in thickness has been removed, while some of the projected strippings will require the removal of nearly 200 feet of overburden as, for example at Locust Mountain. A great deal of coal is obtained by this method which could not be obtained by underground mining, especially in those areas where

the early mining operations left much coal in the ground and a great deal of it in such condition that underground mining is very difficult, dangerous or even impossible.

In some of the bituminous fields of the United States open cuts are extensively worked, particularly in Alabama, Missouri, Kansas, Indiana, Ohio, Pennsylvania, Illinois and Oklahoma. In Missouri over one million tons, or 21.6 per cent of the coal mined in that state in 1916 was mined in this way. Over 12 per cent of the coal mined in Indiana and a considerable amount of that raised in Alabama is worked by this method.

After the stripping is done the coal is usually dug by steam shovels of special type, known as rotary shovels, but in a few cases it is dug by hand.

The main advantages of the stripping method are in the absence of squeezes, falls of roof and dangerous gases with accompanying explosions. There is no necessity for timbering or lighting, and the work may be more easily directed. Experienced men are not necessary except for the management of the steam shovels, and in case of closing down operations the damage by flooding of the pit is not usually so great as the damage suffered by an idle mine. The disadvantages are the necessity of ceasing work in very stormy weather and the collection in the open pits of so much water, and, in the colder climates, of snow. It is difficult to dispose of the overburden in some regions and the abandoned pits are objectionable, but probably not much more so than a surface area which is extensively caved after the mining of shallow seams.

Underground Workings

MINE OPENINGS

In order to reach the coal which lies too deep for stripping operations a *tunnel* or *drift* is driven, or a *slope* or *shaft* is sunk. A tunnel is typically open at both ends but the term is often applied to an opening driven horizontally or nearly so across the measures. In coal mining a drift is usually regarded as an opening driven from the surface in the seam but the term is also used in some cases where the opening does not reach the surface. A shaft is a vertical mine opening driven from the surface. If it is driven from one seam to another it

is known as a *blind shaft*. A slope is an inclined opening usually driven on the coal seam and used as a haulage or other roadway.

Shafts. — A shaft should be placed where it will best serve the maximum portion of the area to be mined and it should be kept away as much as possible from areas which are faulted, highly squeezed or subject to flooding. A shaft may be timbered, bricked, concreted or lined with metal. Timber is commonly employed but many of the modern shafts in large mines are concrete lined while brick is used in many mines, especially in Europe. The advantage of brick or concrete over timber is in their greater durability, in the absence of danger from fire, and, in the case of air shafts, in the fact that they offer much less friction to the air currents since the timbers tend to create local eddies in the current and thus increase resistance to movement.

The shape of the shaft varies with the conditions. A timbered shaft is, as a rule, rectangular while a brick or concrete shaft is usually made circular or elliptical. The size depends chiefly upon the proposed output of the mine, the size of the mine car to be employed and the possibility of the formation of ice in the compartments in winter. The width of the cross section may be from 5 feet to more than double that width, and the length may exceed 50 feet where there are a large number of compartments used in hoisting a big output.

In most shafts there is a compartment set apart for pipes and ladders while the others are used for hoisting.

In sinking a shaft the same methods are employed in coal mining as in metal mining and include the blasting of the rock and its removal by hoisting with windlass or steam hoist. Where the rock is not firm or where quicksand or other running ground is encountered special methods such as piling, freezing or cementing must be employed. A shield may be used in some cases to protect the workmen from falling rock.

The laws of most states require at least two separate openings to all coal mines so that in case of accident men may have a means of escape.

THE ROOM-AND PILLAR-METHOD

Entries, headings, or gangways. — As the term implies this method consists in working out *rooms*, *chambers* or *breasts*, in the seam, leaving

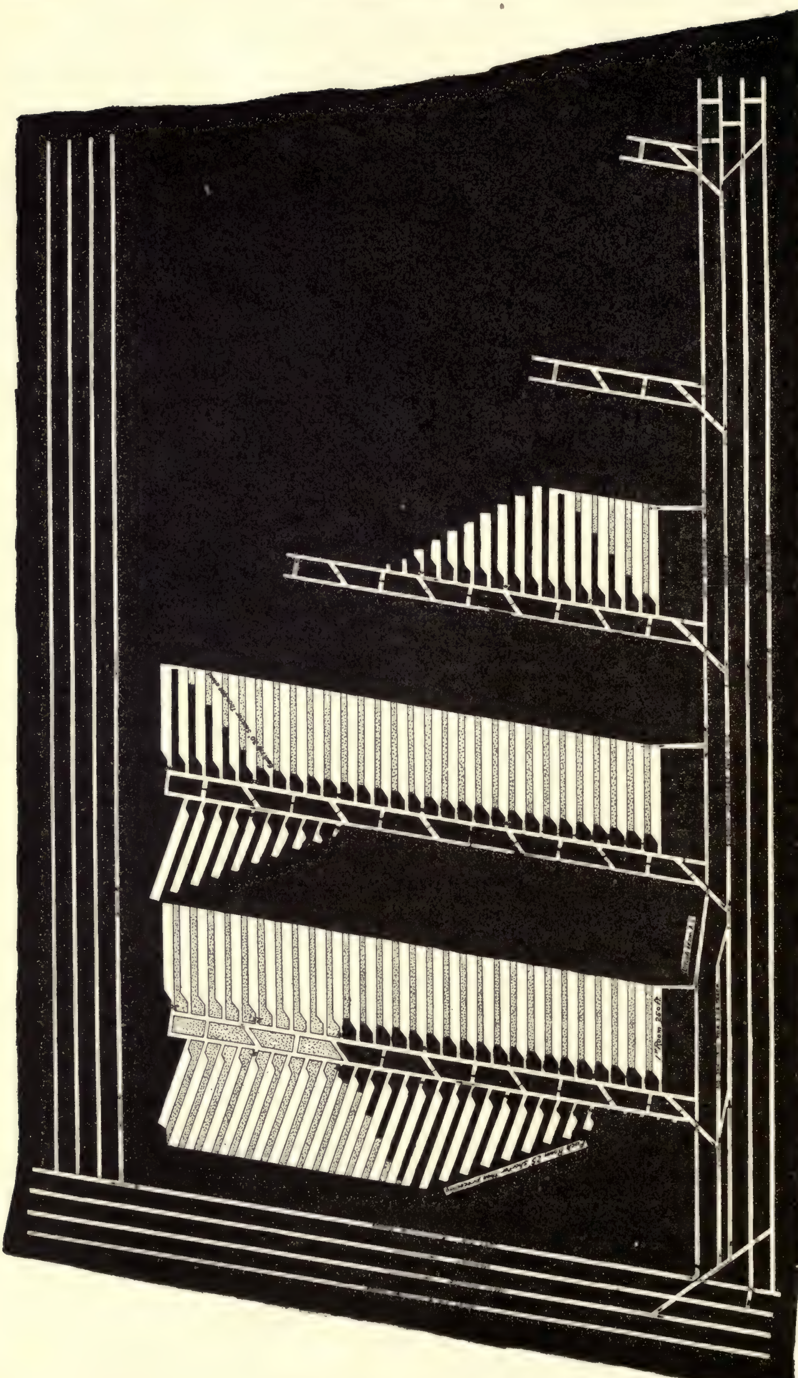


FIG. 84. — Plan of bituminous mine in Pennsylvania showing the four-entry system and the method of drawing the pillars.

portions of the coal between these rooms in the form of pillars to support the roof. The portion of the seam which is to be mined from a certain shaft or slope is first split up into a number of sections by driving passages from the shaft bottom or from the slope as the case may be, (Fig. 84). These passages are known as *main entries* or *main headings* in the bituminous mines and as *gangways* in the anthracite mines of America, and they usually run to the border of the property. They are as straight as possible so as to avoid turns in track or sudden changes in direction of the air currents, and where used for air courses the perimeter should be as small as possible in proportion to the area so as to reduce friction of air current to a minimum. The nearer a square is approached the less the perimeter for the area enclosed. They are about 6 feet high and from 6 to 21 feet wide, according to the thickness of the seam, the nature of the bottom and roof of the seam, the amount of output from the mine and other factors. If the roof and bottom are bad it is more difficult to carry a wide entry and if the seam is too thin so that the roof must be *brushed* down by taking down a lot of draw slate there must be an entry wide enough to furnish some storage space for the waste rock. It usually costs much more to drive narrow entries than wide ones in proportion to the coal taken out as the former operation is classed as *narrow* work and a higher charge is made for all work so classed. The size of the area mined from one shaft where the seam is flat will run from several hundred to two thousand acres or more depending upon conditions, and some main entries are, therefore, of great length. They are timbered, bricked or concreted where necessary to properly support the sides and roof. Timber is more commonly used but concrete is now being extensively adopted in the larger mines for at least the part of the entry near the shaft or slope.

In driving main entries they are usually driven on the dip of the seam, if the seam is inclined, and if it be nearly flat such factors as drainage, direction of horsebacks, direction of joints in the coal or its cleat, and direction of fractures in the roof of the entries affect the direction. From the main entries *cross entries*, *cross headings*, or *butts* are driven, usually at right angles to the main passages. There are some important considerations in laying out the cross entries or butt headings. They must drain properly to the main headings and if possible any grade should be used to advantage in hauling the coal.

In case a syncline or " swamp " occurs in the mine the headings should be run so that the rooms may be driven on the rise from the entry and the coal thus worked down grade to the main haulage lines. In inclined seams the headings are driven so that they follow closely the strike of the seam, allowing for drainage, and each section of the mine in which one or more of these headings is driven off the slope is known as a *lift* or *level.* This term includes all the workings lying at approximately the same level and connected with the slope or shaft at the same elevation.

Entry systems: The number of entries varies greatly in the mines of different regions. There are *single*, *double*, *triple*, *quadruple*, and even *sextuple*-entry systems. The first is seldom used and is not applicable to a large mine. In it a single entry is driven and it serves as the haulageway and intake air course. It is inefficient because an accident in the entry may cut off the circulation of air, the haulage, and the escape of men from the mine.

The double-entry system is very commonly used in America and as indicated by the name the main and cross entries are all driven in pairs. This increases the efficiency of the mine as a double track increases that of a railroad. If one entry becomes blocked the air current and the haulage may be shifted to the other, (Fig. 84 and Plate IX).

The triple-entry system is also frequently used and it has an advantage in that the central passage may be used as the main haulage route and at the same time the intake air course. The other two entries are the return air courses for their respective sides of the mine.

In the four-entry system there are four entries driven side by side; this system is frequently adopted, especially for gaseous mines and those with a large output (Fig. 84). For those mines where endless rope haulage is used it has an advantage as one entry may serve as a haulage road for loaded cars and the other for empties, while the other two are the return air courses. Several different arrangements are possible as one entry may be used for a manway and intake air course, one as a haulage road and intake and the other two as return air courses, or they may be divided so that the four entries are operated as pairs.

In all these systems where two or more entries are used the entries are connected by *cut-throughs*, *break-throughs* or *cross cuts*, which

are openings about the same width as the entries and driven at right angles to the entries, through the pillars separating them. When one of these openings is driven at an inclination less than 90° to the entry it is known in some localities as a *shoofly*, (Fig. 84). The distance between these openings varies with the law requirements of the region, the gaseous nature of the mine and other local conditions. In the entries, spaces must be provided for the temporary storage of cars where they are collected from the working places and made up into trips. These track areas are known as *sidings*, *partings* or *lyes*, and where single track is used for haulage the siding where the cars turn out to pass is known as a *turn-out* or *pass-by*.

Rooms, chambers, or breasts. — The *rooms*, *chambers* or *breasts* are openings in the seam turned off the cross-entries and separated by pillars, (Fig. 84). These rooms are laid out according to a definite system and at stated intervals. The end of the room where the coal

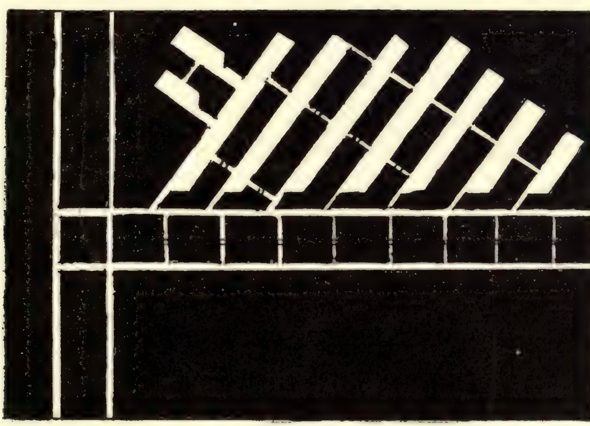


FIG. 85. — Rooms driven at inclination to the entry in double entry mine.

is being mined is known as the *face* or *working face* and the side of the room or entry along a pillar is the *rib*. The terms *inby* and *outby* serve to indicate the direction in the room, the former meaning toward the face and away from the entry and the latter the opposite direction.

When a room is begun an opening known as the *neck* or *mouth* is made from the entry and about the same width as the entry. This is usually at right angles to the entry in flat or steeply pitching seams, but in gently inclined seams the rooms may be inclined less than 90°

to the entry and thus secure a more gradual rise for hauling cars to the face, (Fig. 85). Where the rooms are driven at such an angle their necks must be longer in order to leave sufficient coal in pillars to protect the entry. The direction of the room may also be influenced by the fractures in the roof and by the cleat in the coal. There are several terms describing the relation between the direction of these joints and the direction of the room. When the face is parallel to the main, or face cleat, and the rib at right angles to it the position is known as *face on*. The opposite to face on is *end on*, the position in which the face is at right angles to the face cleat and parallel to the butt cleats. *Half on* is the term used where the face of the room makes an angle of 45° with the face cleats and *short horn* where it makes an angle of more than 45°. In driving *long horn* the face of the room lies at an angle less than 45° to the face cleats. These various positions have their advantages under different conditions because the coal breaks more readily and leaves more lump if mined from a certain direction with relation to the cleats. The gas may escape from the coal more gradually if the face lies across the direction of the main joints rather than parallel to them.

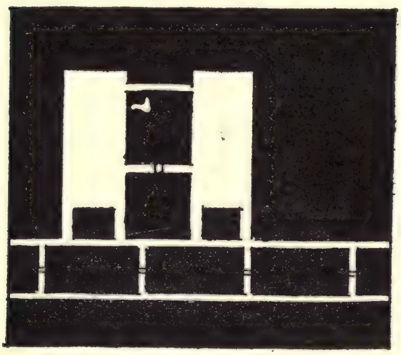


Fig. 86. — Double room and break-throughs.

When the neck of a room has been driven a sufficient distance from the entry, varying from 6 to 25 feet, the room is widened out on one side of the neck at an angle of 90° or less, usually less, (Fig. 84). This side is known as the gob side because the waste rock is usually stored in it and the track is laid along the opposite side. The width of the room will depend upon such factors as the weight of overlying strata, the character of the roof and bottom and the thickness of the seam. A common width is about 20 feet, but it may run from 12 feet up to 40 feet or more. The length of the room usually lies between 150 and 300 feet although rooms are sometimes as much as 600 feet in length. A common length is 250 feet. The presence of gas will usually affect the length of the room to some extent and tend

to shorten it. The rooms are connected by *cut-throughs*, or *break-throughs*, to permit the circulation of air and the movement of the workmen, and in some cases a series of these in line may serve as a haulage road. The more gaseous the mine the more numerous the break-throughs should be. In many fields their number is fixed by law. In the bituminous region of Pennsylvania they cannot be more than 35 yards nor less than 16 yards apart.

In some mines *double rooms* are driven, leaving a pillar of coal between the double necks, (Fig. 86). The main advantage of the double room is in the more extensive working face provided. If there be much waste rock it may be gobbed along the center of the room leaving the tracks along the ribs on either side.

Pillars. — The several types of pillars in a coal mine comprise: the ordinary pillars left between entries and between rooms or breasts; *chain* pillars; *shaft* or *slope* pillars; and *barrier* pillars. A chain pillar is a long wide pillar left along an entry or gangway from which rooms are being driven to protect that opening, and it may be cut through by a number of break-throughs. A shaft pillar or slope pillar is left around a shaft or slope in each coal seam through which the shaft or slope passes, to protect the shaft or slope and the buildings or other structures on the surface from damage. A barrier pillar is left along the border of a property to protect adjacent lands on either side of a property line from caving and from water or gas. The term is also applied to a pillar left in a mine to protect a certain portion of the mine from gas or water or to separate for some other reason this portion from the remainder of the mine.

Size of pillars: The size of any of these pillars depends upon various conditions and can only be determined from experience in the region being worked. The greater the inclination, depth and thickness of the seam, the greater the quantity of water present, the weaker the roof and bottom, the more friable the coal, the more faulted the overlying strata, and the longer the pillars must stand, the larger they must be, other things being equal. The approximate weight of the overlying strata may be figured by averaging the specific gravity of the rock and computing the weight of the column of rock of the proper size and depth, but even then the effects of arching or bridging of the heavy beds in the series will not be taken into account. The average specific gravity of sandstone may be taken as 2.3 and that of

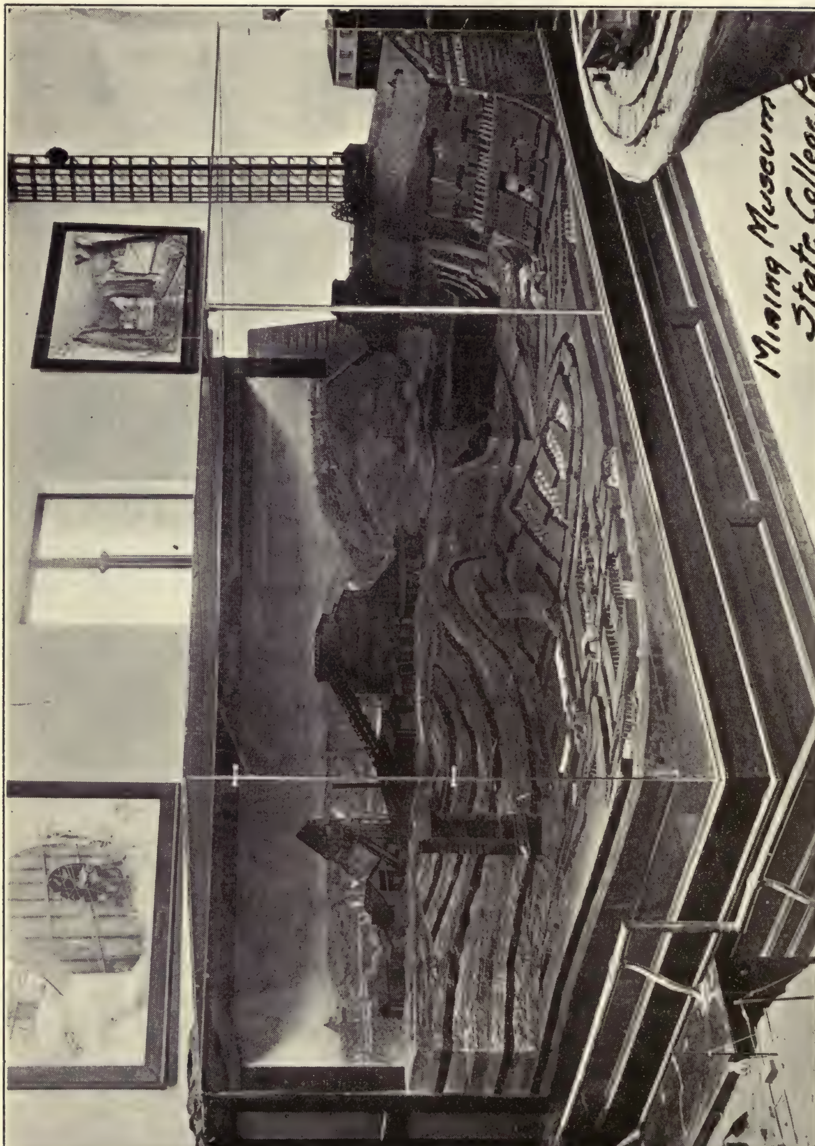


PLATE X. — Model of anthracite mine workings showing the coal seams as black bands and the intervening gray. It illustrates stripping and mining operations in both flat and steeply pitching seams.

shale as 2.5, which makes a cubic foot of sandstone weigh about 140 pounds and a cubic foot of shale approximately 160 pounds.

The distance between entries is usually made from 20 to 60 feet. Under certain conditions it is necessary to leave extra entry pillars to protect the entry, and these may be very wide, sometimes exceeding 100 feet. The room pillars vary from 6 to 90 feet in width in various mines, depending upon conditions and the methods adopted in these mines. The pillars are much wider at the *stump*, which lies between the necks of the rooms than elsewhere. A common width is 20 to 30 feet for these pillars.

The width of barrier pillars, like that of all others, varies with the conditions, the three main ones being the inclination and depth of the seam and the amount of water in the adjacent workings. A rule generally used as a guide by inspectors and engineers in the anthracite region of Pennsylvania is as follows: *Multiply the thickness of the deposit in feet by 1 per cent of the depth below drainage level and add to this 5 times the thickness of the bed.* In the bituminous region of Pennsylvania the mine law fixes the width of the pillar according to the conditions relating to water pressure.

In some of the steeply pitching anthracite seams it is probably impractical to attempt to leave a barrier pillar which will be capable of supporting the load and holding back the water in deep basins, when the seams have been extensively mined. The oxidation of the coal where circulating water comes in contact with it tends to weaken the pillar in time.

There are many rules for establishing the size of shaft pillars. As in the cases of the other pillars mentioned it is necessary to leave a large margin of safety as it is extremely important to protect the shaft bottom and the structures on the surface from any damage. Among the rules for the size of shaft pillars which are most generally accepted is Dron's, which allows for a good factor of safety. Dron's Rule is as follows: *Draw a line enclosing all surface buildings that should be protected by the shaft pillar. Make the pillar of such a size that solid coal will be left over the whole area enclosed by this line and for a distance beyond the line equal to one-third the depth of the shaft.* The formula for computing the diameter of the shaft pillar by this rule is as follows: $D = s + \frac{2d}{3}$, where s is the diameter of the circle

or square enclosing the structure on the surface and d is the depth of the shaft, in the same units of measurement.

Some of the other rules employed are as follows:

Andre's Rule: *Minimum diameter of circular pillar or side of square pillar should be* 35 *yards to a depth of* 150 *yards. Add* 5 *yards for each* 25 *yards of additional depth.*

$$D = 35 + 5\left(\frac{d - 150}{25}\right)$$

Mining Engineering Rule: *Radius of circular pillar or half side of square pillar, in yards is equal to* 20 *yards plus one-tenth of the product obtained by multiplying the depth of shaft, in yards, by the square root of the thickness of the seam in yards.*

$$D = 2\left(20 + \frac{d \times \sqrt{t}}{10}\right) = 40 + \frac{d \times \sqrt{t}}{5}$$

where d = depth of shaft and t the thickness of the seam.

Foster's Rule: *Radius of circular pillar, or half side of square pillar in feet, is equal to* 3 *times the square root of the product of the depth of cover, in feet, and the thickness of the seam in feet.*

Hughes Rule: *For the diameter of a circular pillar or the side of a square pillar allow* 1 *yard for each yard in depth.*

Central Coal Basin Rule: *Leave* 100 *square feet of coal for each foot that the shaft is deep, a main entry of average width being driven through this pillar. If the bottom is soft the result is increased by one-half.*

$$D = \sqrt{100\, d}$$

Modifications of The Room-and-Pillar Method

The pillar-and-stall system. — This system is also known in some places as bord-and-pillar and post-and-pillar, although the systems are not the same in all respects. The pillar-and-stall system differs from the method already described in the smaller size of the rooms in proportion to the size of the pillars. The stalls are narrow rooms usually 10 to 15 feet wide with pillars about the same size in some cases. In other cases the rooms are driven about 10 feet wide on 100-foot centers and the pillars are then split a great number of times. In some cases double stalls corresponding to double rooms are driven.

This system is used to advantage in some seams with bad draw slate and a bottom rock inclined to heave. In some places the stalls are driven full width from the entry without a neck. One form of this system is used in the Connellsville region of Pennsylvania.

The panel system. — The principle adopted in the panel system is to divide the area to be mined into square or rectangular blocks by entries driven at right angles to each other, (Fig. 87). These blocks are subdivided into a large number of smaller blocks and thus the

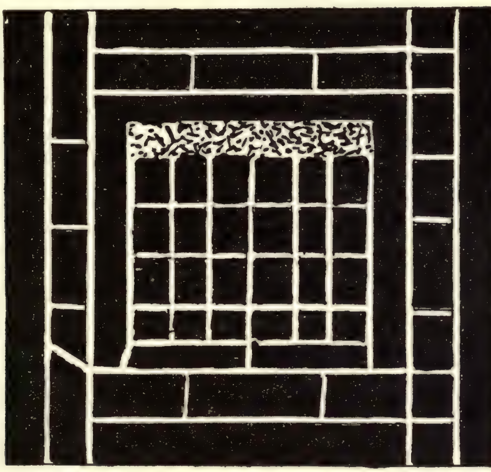


FIG. 87. — The panel system.

original section is worked out as a unit. A large solid pillar is usually left surrounding the panel on three sides, serving as a barrier in case of fire or accident and controlling the air circulation. The system has the disadvantage of much narrow work but the advantage of giving complete control of the ventilation in that section of the mine and of permitting the block to be handled as a separate unit in case of accident.

Anthracite mining in Pennsylvania. — Since special methods must be employed in seams dipping more than 10° a description of some of the methods employed in the anthracite region of Pennsylvania will serve to illustrate the main variations from those employed in flat-lying seams. In general the room-and-pillar method is used, but the rooms are known as *breasts* or *chambers* and the entries as *headings*

or *gangways*. The *breasts* are driven to the rise and nearly up to the next higher gangway, (Fig. 88).

One of the main problems confronting the miner in inclined seams is that of transporting the coal in the breast from the face to the gangway. The following methods are employed: If the seam does not pitch more than 10 or 12° and the breasts are driven at an inclination to the pitch the car may be taken to the face and lowered by hand, by mule or motor. These means cannot be employed in a seam pitching more than 5 or 6° if the breast be driven on the full pitch. If the breast be driven on the full pitch the car may be lowered by windlass up to 10 or 12° inclination. Jig roads are also used under similar conditions.

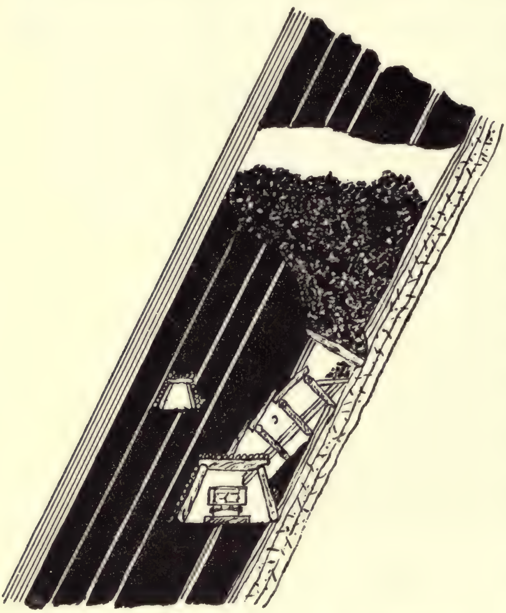


FIG. 88. — Mining anthracite in Pennsylvania in steeply dipping seam. (After H. H. Stoek, U. S. Geol. Survey.)

The buggy system. — The buggy system is often used in thick seams where there is plenty of head room. This system consists in the use of a small car which can be taken to the face by hand or by aid of a windlass where the seam pitches from 10 to 18°. The coal is loaded on the buggy, taken down the breast and dumped on a platform, from which it is shoveled into the mine car in the gangway. In some cases two buggies are used and the coal is transferred from one to the other and thus lowered by stages. This method is costly in labor and coal broken.

Chutes. — In seams dipping between 15° and 30° the coal is usually sent down sheet-iron *chutes* to the gangway. These chutes are laid in the center of the breast with a row of props along either

side and the gob is stored between these props and the ribs. The men travel along the chute. When the seam dips more than 30° the coal will usually slide of its own weight and it is necessary to place an obstruction at the bottom of the chute in the neck of the chamber to hold the coal back. The structure employed is known as a *battery*, and a breast with such an arrangement as a *battery breast*, (Fig. 89): The coal is drawn out through the battery at such a rate that plenty of broken coal remains in the breast to permit the men to stand upon it and work at the face. This avoids the necessity of building a timber stage on which to work. In some cases the breasts are driven with double necks and two batteries are then constructed, (Fig. 90). This arrangement has the advantage where the seam is steeply inclined, of leaving a large pillar in the center of the lower end of the breast to support the weight on the battery. In the battery breasts a manway must be provided as a separate opening driven through the coal or as an opening through the battery. In the breasts the men travel along the chute which is lined with posts securely set into the floor and roof of the seam.

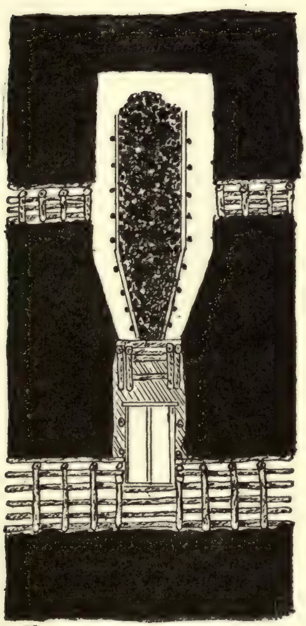


FIG. 89. — Single battery breast in anthracite mine.

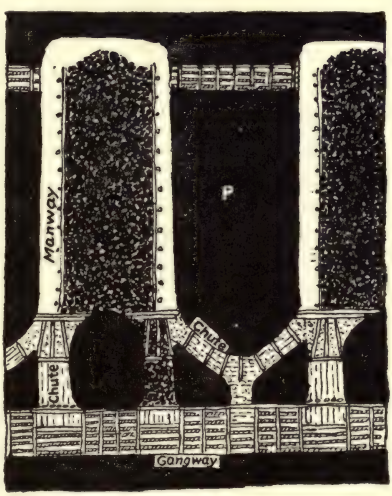


FIG. 90. — Double battery breast.

In the working of contiguous seams or of seams lying parallel and

close together but separated by more than about 3 feet of rock, the coal in the upper seam is carried to the gangways in the lower seam through *rock chutes*, (Fig. 91). If there be less than about 3 feet of rock separating the seams they are usually worked as one seam with a parting, and the rock is mined out. Where contiguous seams are worked the working of the upper seam is usually completed first and the pillars robbed before the underlying seam is worked beyond the driving of gangways and airways.

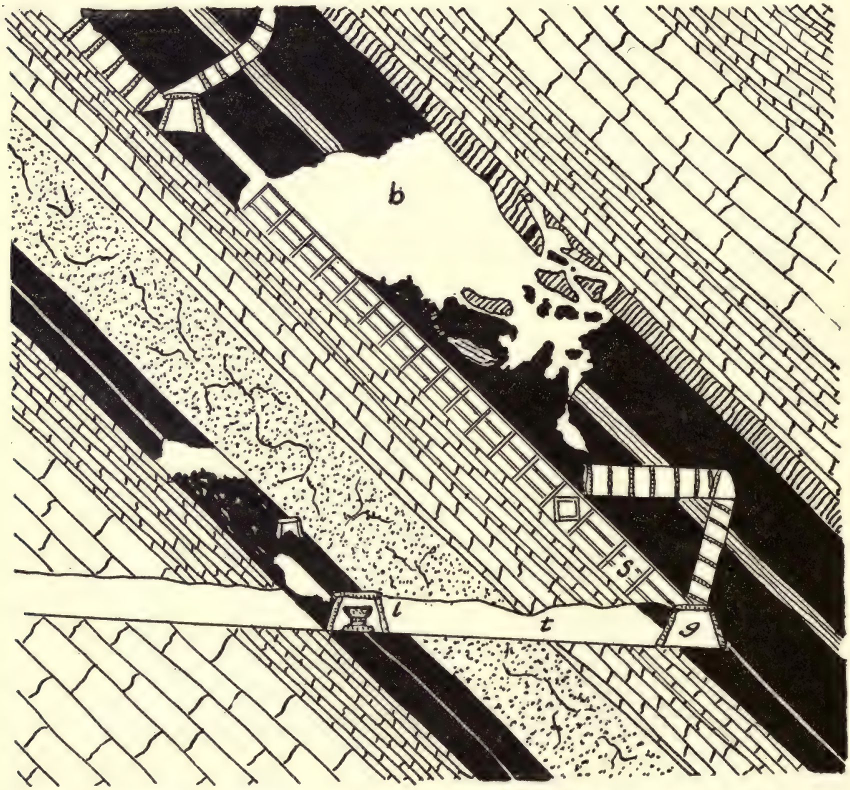


Fig. 91. — Method of working contiguous seams through a horizontal rock tunnel. (After H. H. Stoek, U. S. Geol. Survey.)

Pillar Drawing

During the *first mining* a large portion of the coal is left in the pillars and it must be extracted later. The process of removing the coal in the pillars is known as *robbing pillars* or *pillar drawing*. It is one of the more hazardous features of mining operations and

the work should be attempted only by the more experienced miners. The percentage of coal left in the pillars after the first working varies from 30 to 65 per cent of that originally in the seam, and in some cases where the thickness of the seam is favorable, the gas not excessive, and the roof and bottom good, as much as 98 per cent has been removed by final working.

There are several systems of robbing pillars and the one adopted depends largely upon the local conditions. In some cases a break-through is made at the inby end of the pillar and the pillar is gradually removed until only the stump is left near the entry. Props are used to partially support the roof as the coal is removed and as the work advances the props are recovered and the roof allowed to cave. Care must be exercised in supporting the roof so as to keep sufficient pressure on the coal to help break it but not enough to crush the pillar. The roof should be broken at the stumps if possible, so as to relieve the weight on the entry pillars. Gas should not be allowed to collect in the gob for an indefinite period as it may escape into the workings or take fire. Another method of robbing pillars consists in splitting the pillars one or more times and then drawing them back as described above.

In some mines the pillars are drawn out in panels and in others the workings are driven to the edge of the property and the pillars drawn back on a retreating system. In any case the ends of the pillars being drawn back should be kept in a nearly straight line so as to keep the roof supported and also to let it cave in a systematic manner, (Fig. 84). This lessens the danger to the miners and avoids the loss of coal.

THE LONGWALL METHOD

There are two main systems in longwall mining and several modifications of these systems to suit particular conditions. The systems are known as the *advancing* and *retreating* systems. In the former the workings are advanced from the shaft pillar toward the border of the property and in the latter the main entries are driven to the border of the property and the workings are then carried back toward the main shaft. The main features of the longwall method are the removal of practically all of the coal as the face advances and the maintaining of a continuous working face around the workings, (Fig. 92). The waste rock is used to fill up the space from which the coal has been

removed and the roadways are maintained by *pack-walls* on either side of them, made of waste rock. These piles of rock are known as the *road packs* and those in the areas between the roads as *gob packs.* The main roads run diagonally from the shaft pillar like the spokes of a wheel, and the intervening areas are subdivided into smaller and smaller sectors by subsidiary roads.

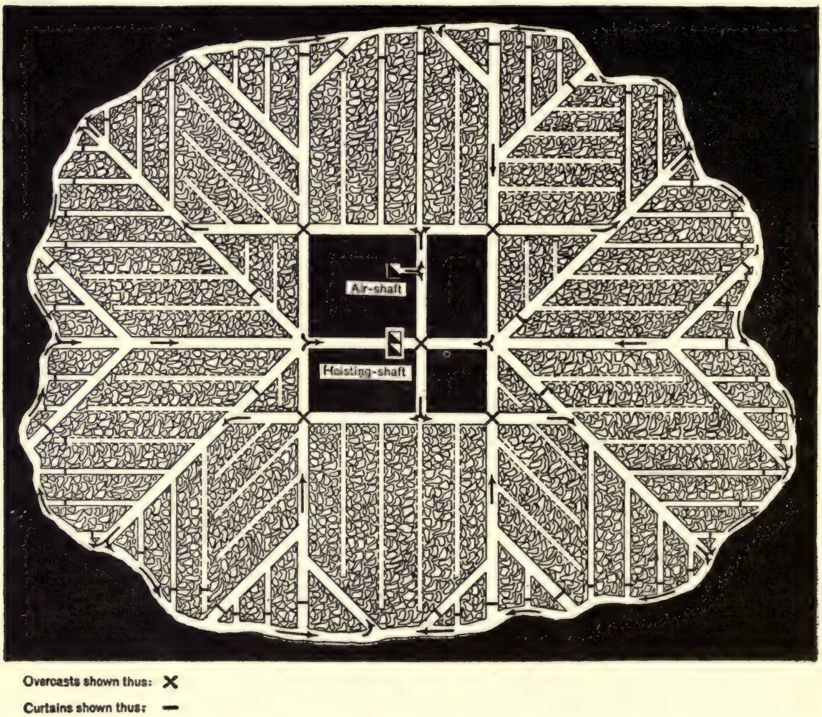


FIG. 92. — Plan of a longwall mine showing direction of ventilating current. (After Swift; from Bull. 13, Ill. Geol. Survey, University of Ill. and U. S. Bur. of Mines.)

In this method little of the coal is blasted from the face, the roof pressure being used to break it down after the coal is undercut. It is necessary therefore that the face be advanced uniformly and continuously.

This method is particularly adapted to thin seams where the roof settles and the bottom tends to heave, since the waste rock is used for packing and the coal can all be removed in the first working. It also leaves the surface in better condition than the room-and-

pillar method because the strata settle more uniformly. A larger percentage of the coal can be extracted in most cases than with the other system. Less timber is needed for roadways than in other methods and as a rule this method brings quicker return for capital and labor.

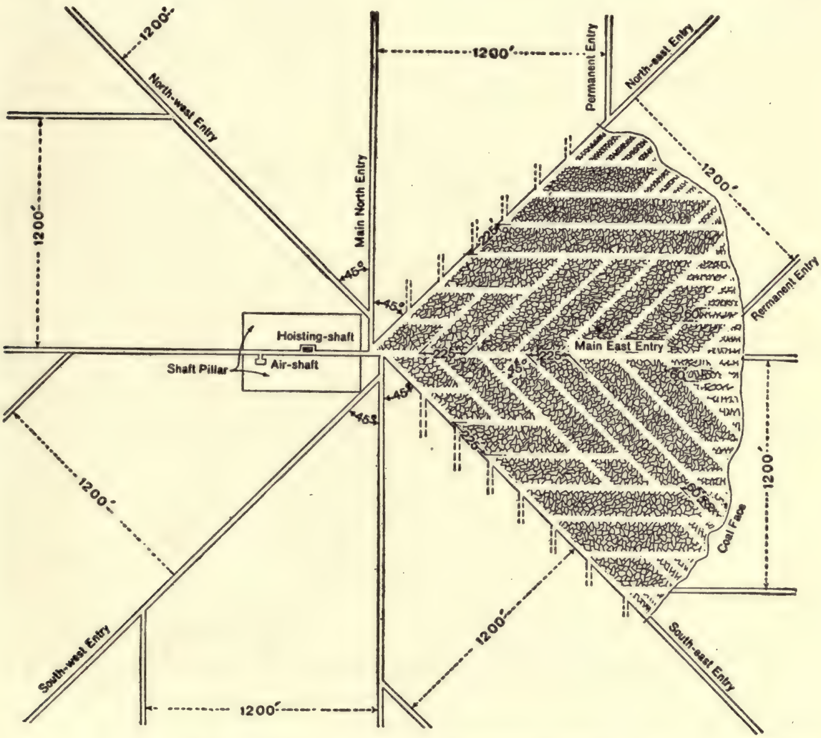


FIG. 93. — Plan of longwall mine with auxiliary permanent entries. (After S. O. Andros.)

The disadvantages of the longwall method lie in the fact that more experienced miners are needed to operate the mine successfully. A section of the mine cannot be controlled as with the other methods and the mine suffers more from idleness or from irregular work of men at the face. It is more difficult to get into operation and a great deal of trouble is often encountered in getting the roof to break properly around the shaft pillar or at the limits of the property as the case may be. It is only successful where there is plenty of waste rock, although in France it is employed where rock must be brought in

from the surface in great quantities. There are immense quarries in central France from which the rock is taken for this purpose, (Fig. 96). This increases the expense considerably. In the United States the longwall method is used comparatively little. There are a good many longwall mines in Colorado and some of the other western states, a number in Illinois and a few in some of the eastern states. Certain modified systems used in the anthracite region of Pennsylvania are known as the *chamber longwall*, *lateral longwall* and *block longwall* systems. These are operated on a rectangular or sort of panel arrangement, (Figs. 94 and 95).

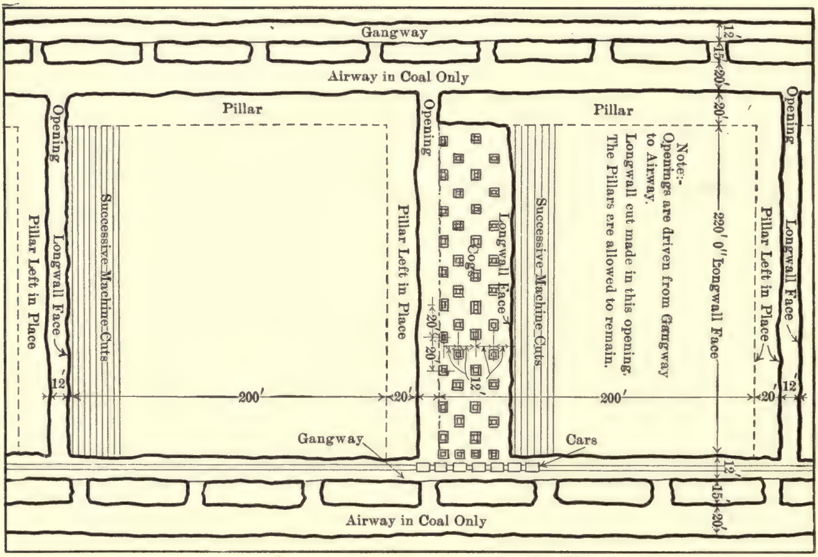


FIG. 94. — Block longwall system. (By courtesy of the D. & H. Company, Scranton, Pa.)

Mining in thick seams. — When seams are very thick it is necessary to mine them in benches or with some sort of shrinkage stope system. The system which has been most successful is a modified form of the longwall in which the seam is worked in benches and the open spaces packed full of waste rock, (Fig. 97).

Breaking the Coal at the Face

Several methods are employed in breaking the coal at the face. When the longwall method of mining is adopted the coal is undercut

by a longwall machine and the roof is allowed to settle gradually so as to break down the coal. In the room-and-pillar method the coal is undercut by a coal cutting machine or by miners' picks and is blasted or wedged down, (Fig. 98). In many cases the coal is *sheared* as well as undercut. Shearing consists in making a vertical cut along the side of the room or entry as the case may be in order to keep the wall straight and uniform. Some of the latest machines will not

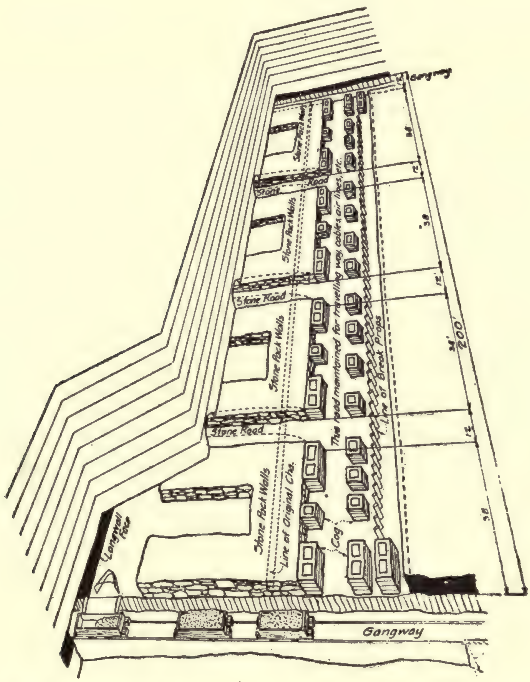


FIG. 95. — Development of a longwall operation in the anthracite region. (By courtesy of the D. & H. Company, Scranton, Pa.)

only undercut the coal but also shear it, and it is expected that in the near future they will be so constructed that they will also successfully break down the coal. The depth of the channel which is cut along the bottom of the seam, or along a parting in the coal as the case may be, may reach 6 feet or more, but it depends somewhat upon the nature of the coal and roof pressure. When it is done by hand it must be wide enough to permit a man to lie in it on his side and work

a pick, the seam above him being kept from closing down by a short prop. After the coal is undercut it is shot down or wedged down.

In some cases coal is shot from the solid, and this is necessary in many anthracite mines. This method has the disadvantage of breaking the coal up so that much more slack and less lump coal results. There is also more danger in firing owing to the heavy charges necessary to blow the coal down. The production of a greater percentage of slack does not matter so much if it is to be used for coking but it lowers the value of the coal very greatly for domestic and steaming purposes. A great deal of care and judgment is necessary in placing the holes which are made by augers or hammer drills, as their depth and arrangement affect the amount of coal shot down, the conditions in which the broken coal occurs and the safety of the miners, especially when black powder is used.

Mining Machines

There has been a rapid development in coal mining machines in recent years. The latest coal-cutter has been so developed that it can undercut and shear the seam, can cut out a sulphur band or a parting in the seam and can be operated much more readily than the earlier types. There are also loading machines which apparently work quite successfully under certain conditions. The tendency has been to get away from the pick machines, or punchers and adopt the continuous cutting types. The application of electricity has been responsible for a great development in mining machines and it is now possible to use electric machines in gaseous mines. According to the latest report of the Department of Mines of Pennsylvania, the percentage of bituminous coal mined in this state by compressed air machines in the year 1899 was 21.22, and in 1917 it was 9.03. In the same years the percentages mined by electrical machines were 18.38 and 45.14 respectively. In the same years the percentages mined by hand were 60.40 and 45.83.

The use of cutting machines in the anthracite region has developed more slowly than in the bituminous region of Pennsylvania, owing to the difficulty in cutting the harder coal and in moving the machines on the steep pitches, but the machines are now successfully used in parts of the region.

It seems probable that we will see a machine in the not far distant future which will undercut, shear, break down and load the coal where the conditions are favorable.

Mining Methods in Foreign Countries

Europe. — The longwall method is much more generally used in Europe than in America, and on the European continent it is used almost entirely. According to G. S. Rice[1] the typical American room-and-pillar method is not used in Europe except in a few places in Wales, where it is known as the pillar-and- (single)-stall method, and

FIG. 96. — Open cut at Commentry, France, from which coal has been mined and most of the rock used to fill the mines. (Photo by E. S. Moore.)

in Upper Silesia where it was formerly used rather extensively but is now largely abandoned for the longwall method. The pillar-and-double-stall method was formerly used to some extent in Scotland and in Wales but it has also been nearly abandoned for the longwall method. In South Staffordshire a method known as the *square-chamber* method has been used in the Ten Yard seam. In this method the coal is worked by chambers 46 yards wide and up to 200 feet long with thick pillars between them. Four to six coal pillars are left standing in rows through the chamber.

[1] Rice, G. S., Coal-pillar drawing methods in Europe. Trans. Amer. Inst. Min. Met. Eng., New York Meeting, Feb. 1921.

The bord-and-pillar or stoop-and-room method is common in the north of England, in Scotland and to a lesser extent in Wales. In Upper Silesia it is used in a modified form where the hydraulic sand filling system is in use in the thick seams. The writer has visited mines near St. Étienne, France, where the modified longwall method was being used and the waste rock of the mine was supplemented by rock brought in from the surface so that the space mined out could be completely filled up as fast as the coal was removed, (Fig. 96).

Australia.[1] — On this continent the pillar-and-bord system is very largely used although the longwall method is found in a number of mines. In several places both methods are used in the same mine.

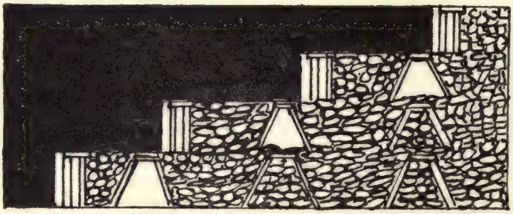


Fig. 97. — Bench working in thick seams, with stone packs.

In some mines one method is used in one seam and the other method in an underlying seam, depending upon the thickness of the coal, the abundance of waste rock and other factors.

Mine Haulage

Haulage in mines is performed by animals, electric motors, compressed air locomotives, steam locomotives and cables. There are advantages in all these sources of power under certain conditions. Some companies have successfully taken the cars to and from the face with a motor while others have found it uneconomical to use a motor for other purposes than hauling trains of mine cars considerable distances. In the latter case a mule is used for gathering the cars into trains. Whether a motor may be used successfully in gathering seems to depend very largely upon the thickness of the seam and the ease with which the tracks are kept open and in good condition.

Rope or cable haulage is of two types, *endless* and *tail*. In the

[1] Power, F. Danvers, Coalfields and collieries of Australia. 1912.

former type the cable runs continuously and the car is arranged so as to grip the cable. This works successfully in some mines but unsuccessfully in others. The straightness and regularity of the entries has a good deal of influence on this system. With the tail rope the cars are hauled in opposite directions by separate ropes.

Conveyors are now being used successfully in some mines, especially in some of the thin seams in the anthracite region of Pennsylvania. Scrapers have also been used to some extent in gathering

FIG. 98. — Sullivan Ironclad alternating current mining machine in operation undercutting a seam. (By courtesy of the Sullivan Machinery Co.)

coal. A remarkable conveyor, about eight miles in length is being installed by the H. C. Frick Company for transporting to the river the coal from several mines. It runs underground and the great belt is driven by a series of motors connected with each other by automatic control systems. It may revolutionize this type of transportation.

Hoisting

Hoisting of coal is usually accomplished by raising the mine car to the tipple and dumping it. Some mines, however, have operated

10-ton skips very successfully.[1] Some of the advantages claimed for skip hoisting over a self-dumping cage are: a larger capacity for coal and rock; smaller shaft necessary; lower rope speed and power consumption; and fewer men. Some of the objections commonly made to skip hoisting are: the greater breakage of coal, although this does not appear to be necessary; excessive dust raised by dumping at bottom of shaft; necessity of a cage for hoisting men and materials; difficulty in docking and inspecting the coal; and difficulties in handling waste rock on the surface.

FIG. 99. — Electric haulage. A trip leaving the mine of the Ebensburg Coal Company. (Photo. by courtesy of J. F. Macklin, Pres. Ebensburg Coal Co.)

Mine Gases[2]

Ordinary pure air contains about 20.93 per cent by volume of oxygen, 79.04 per cent nitrogen, 3 parts in 10,000 of carbon dioxide and small amounts of argon, helium and other gases. Water vapor is present in varying amounts depending upon temperature and pressure and the presence of water in the neighborhood. The oxygen is the most active chemical agent in the atmosphere and it unites with

[1] Allen, A., and Garcia, J. A., Skip hoisting for coal mines. Trans. Amer. Inst. Min. and Met. Eng., New York Meeting, Feb. 1921.

[2] Beard, J. T., Mine gases and explosions. John Wiley & Sons, Inc., 1908.

metals causing them to deteriorate, as in the case of iron rusting. Oxygen is given off by plants, but when animals breathe slow combustion occurs as in a fire and the carbon in their systems unites with the oxygen to produce carbon dioxide. Nitrogen is an inert gas and serves the purpose of diluting the oxygen of the air.

In some mines the air is fairly pure and an open light may be carried without danger. In others there is an abundance of methane and carbon dioxide and dangerous quantities of carbon monoxide and hydrogen sulphide, making it unsafe to enter the mine at all with an open light and dangerous to enter it with a closed light unless the ventilation is good.

Carbon dioxide. — Carbon dioxide (CO_2) has a molecular weight of 44 and a specific gravity of 1.529. Being heavier than air it naturally settles to lower levels when with lighter gas, and this explains why animals may be overcome in low places where this gas has collected while at higher points in the same region they may be quite safe. It should be borne in mind, however, that this may not always be true for the location of the gas in mines since the air currents and the source of the gas may have some influence on its gathering point. It is a product of combustion from fire and the lungs of animals. It may also be given off during the decay of vegetal matter and this explains the presence of a considerable amount of it in the mines where oxidation of the coal is in progress and where it has been imprisoned in the coal seam since its formation from the altering vegetal matter. A certain amount is given off by the breathing of the men and the horses or mules in the mine and by the burning of the lamps.

Black damp or *choke damp* is a mixture consisting chiefly of nitrogen and carbon dioxide with a little oxygen.[1] It is not explosive or poisonous but its danger lies in the fact that it excludes the oxygen so that a sufficient quantity does not reach the lungs of animals. According to W. G. Duncan, average black damp contains 85 to 95 per cent nitrogen and the remainder is chiefly carbon dioxide. The average composition of the mixture is about 90 per cent nitrogen and 10 per cent carbon dioxide. It is, therefore, impossible for an animal to live or a light to burn in this gas.

The presence of carbon dioxide may be detected by an ordinary

[1] Burrell, G. A., Robertson, I. W., and Oberfell, G. G., Black damp in mines. U. S. Bur. Mines, Bull. 105, 1916.

lamp or candle which requires 17 per cent of oxygen, but an acetylene lamp is not extinguished until the oxygen is reduced to about 12 per cent. When 3 to 4 per cent of the dioxide is present most people begin to feel its effects in headaches or other derangements, and real distress may be caused by 5 to 6 per cent of the gas in the air. Where carbon dioxide is present owing to exhalation of animals it is not only this gas which causes the trouble but also the deficiency in the oxygen which has been removed by breathing.

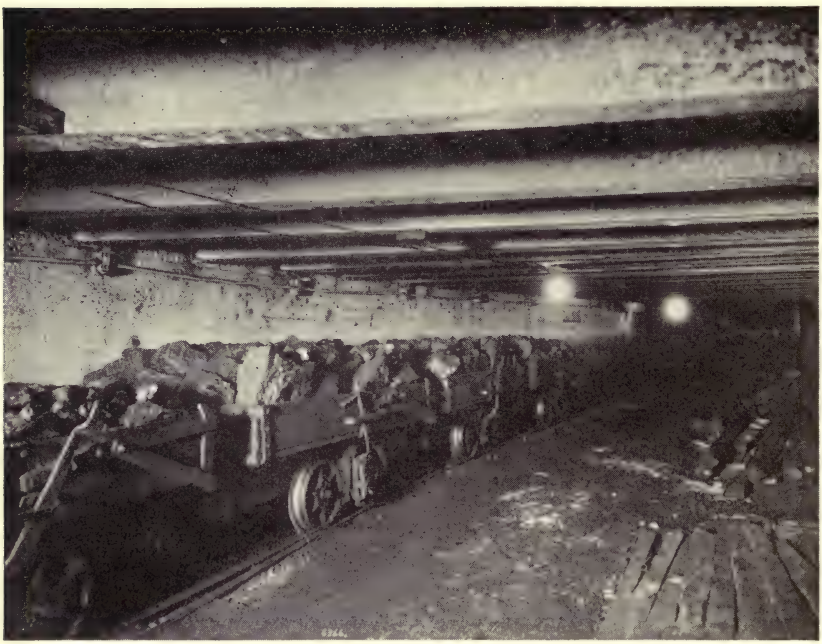


FIG. 100. — Shaft bottom of Jerome Shaft No. 2. Hillman Coal and Coke Co. (By courtesy of the Hillman Coal and Coke Co.)

Carbon monoxide. — Carbon monoxide (CO) is an odorless, colorless gas with a molecular weight of 28, a density of 14, and a specific gravity 0.967. It is, therefore, slightly lighter than air. Its rate of diffusion compared with air is 1.0149 and its ignition point 650° C. When mixed with air in any proportions it forms *white damp*. Unlike carbon dioxide it is a deadly poison, the effects in some cases being sudden, in other cases delayed. It requires only about $\frac{1}{20}$ of 1 per

cent of this gas in air to cause dizziness, headache, shortness of breath or other effects, and $\frac{2}{10}$ may be dangerous, while $\frac{4}{10}$ of it is almost sure to be fatal. The gas attacks the haemoglobin of the blood and 60 to 70 per cent saturation of the blood is fatal. It usually takes from 5 to 6 hours to free the blood after a serious case of poisoning. The effect on the blood is to turn it a pink color. The best treatment is to remove the patient into pure air and apply heat to the body by wrapping up in warm blankets or applying hot-water bottles. In serious cases of poisoning it may be necessary to use pure oxygen mixed with 10 per cent CO_2. To test mine gas for the presence of CO a small animal such as a mouse or canary bird is used, the latter being the best indicator. Experiments by the United States Bureau of Mines[1] have shown that in air containing carbon monoxide canaries and mice behaved as follows:

TABLE SHOWING THE EFFECT OF CARBON MONOXIDE ON ANIMALS

Percentage in air	Canaries	Mice	Chickens	Dogs	Guinea pigs
0.10	No. tested 8; 1 affected in 12 min., 2 slightly affected in 4 hours.	No. tested 7; 1 distressed in 30 min., 6 showed no distress in $2\frac{3}{4}$ hours.	No. tested 1; no effect in $2\frac{3}{4}$ hours.		
0.15	No. tested 4; affected in 5 to 30 min.		No. tested 1; affected in 45 min.	No. tested 1; no distress in 45 min.	
0.20	No. tested 12; 1 distressed in 35 min., 11 in 2 to 6 min.	No. tested 6; 1 distressed in 40 min., 5 in 6 to 12 min.	No. tested 4; distressed in 10 to 45 min.		No. tested 1; slightly distressed in 5 min.
0.35	No. tested 2; 1 distressed in 1 min., 1 in 2 min.	No. tested 2; 1 distressed in 2 min., 1 in 3 min.			No. tested 1; distressed in 4 to 9 min.
0.50					No. tested 8; distressed in 2 to 9 min.

It is evident that all animals of the same species are not affected to the same degree. If an animal becomes accustomed to small amounts

[1] Burrell, G. A., Seibert, F. M., and Robertson, I. W., Effects of carbon monoxide on small animals. U. S. Bur. of Mines, Tech. Paper 62, 1914.

of the gas it is more resistant to future attacks. Small animals are more readily affected than human beings but not in proportion to their weight. The flame of a safety lamp is not affected by less than 1½ per cent of this gas and about 2 per cent is necessary to show a cap. This cap is similar to that of marsh gas. An instrument known as the M-S-A Carbon Monoxide Detector has recently been put on the market; it is very sensitive to this gas and is supposed to indicate within ten seconds any percentage of the gas from 0.05 to 1. Carbon monoxide is explosive when mixed with air in proportions of about 15.5 to 75 per cent, but the presence of carbon dioxide and marsh gas affects these limits by respectively raising and lowering them.

Carbon monoxide is formed by incomplete combustion of carbon in a fire when the oxygen supply is deficient, by the explosion of some types of blasting powder such as those deficient in saltpetre and by the partial oxidation of organic material. The first process is the most important producer of the gas.

Methane. — This gas is also known as marsh gas (CH_4), and when mixed with air it forms *fire damp.* Its molecular weight is 16 and its specific gravity 0.53. It is thus much lighter than air. It is non-poisonous, tasteless, odorless and colorless. It will not support combustion but it will burn with oxygen, producing water and carbon dioxide, when the proportions of the gas vary from 1 volume of gas to between 3.5 and 30 volumes of air, the greatest explosive intensity being reached when the proportions are 1 volume of methane to 9.5 volumes of air. The cap produced on the flame of a safety lamp is the means usually employed in detecting the presence of the gas and the following table shows how the cap develops with the varying percentages of the gas present in the air:

Percentage of methane	*Height of cap and flame*
1	Base of cap forming
1½	¼ inch
2	⅜ to ½ inch
2½	⅝ inch and slightly luminous top
2¾	¾ inch
3	1¼ inches
3½	1½ to 1¾ inches
3¾	Up in gauze

An increase in moisture lowers the explosibility of fire damp and a mixture of 1 part of carbon dioxide with 7 parts of an explosive mixture

of air and marsh gas makes it non-explosive, or 1 part of nitrogen to 6 parts of a similar mixture produces the same result.

Marsh gas is abundant in some mines but almost entirely absent in others. It is given off by the coal and it results from the alteration of the vegetal matter in forming coal as indicated in a general way in the following equation:

$$\underset{\text{Lignite}}{C_{57}H_{56}O_{10}} - (3H_2O + CO_2 + 2CH_4) = \underset{\text{Bituminous coal}}{C_{54}H_{42}O_5}$$

As previously mentioned, one mine in the anthracite region of Pennsylvania has produced as much as 2400 cubic feet of methane per minute. (For further notes see discussion of gases under the Chemical Properties of Coal, Chapter II.)

Hydrogen Sulphide. — Hydrogen sulphide, or sulphuretted hydrogen (H_2S) occurs in mines in small amounts and when it is mixed with air the mixture is known as *stink* damp or *stone* damp since it has a very strong and disagreeable odor. It results in very small amounts from blasting, especially where black powder is used and it is also set free through the decay of organic matter. The odor of rotten eggs is largely due to the presence of this gas. It may also be generated by the action of acids on sulphur compounds. The gas will not support combustion but it burns in air with a pale blue flame, the temperature of ignition being 333.3° C. or at red heat. When mixed with one-half times its own volume of air it burns with explosive force and with 7 volumes of air it explodes violently. It produces headache, nausea and the loss of the sense of smell, and if inhaled in sufficient quantities results are fatal. The amount necessary to produce death in a human being is about 1 part by volume to 200 parts of air. Canary birds are sensitive to about .05 per cent in air. Treatment consists in removal to a plentiful supply of fresh air, and in severe cases a little chlorine gas may be administered to aid recovery.

Hydrogen. — This gas may be formed in small amounts in mines as a result of incomplete combustion in mine fires or in explosions, but it seldom occurs in noticeable quantities. Other rarer gases, including some of the paraffin series, occur in very small quantities in mines.

Safety Lamps

Various methods have been devised for the lighting of mines, from the torch and the flint mill which generated sparks by contact of a

steel wheel with a piece of flint, to the high candle power electric light of the present day. In gaseous mines it is necessary to have a closed light and this gave rise to the safety lamp which is now found in such great variety. The structure of the safety lamp is based on the principle of a protecting envelope through which air will pass but which will prevent the gases outside of the lamp from becoming heated to the temperature of ignition. The first safety lamp was invented by Clanney in 1813 and air was forced into it through a water seal by means of a bellows. The Davy safety lamp was invented by Sir William Davy two years later and had a wire gauze around the flame to conduct the heat away so that the gases outside of the lamp would not take fire. Credit is also due to George Stephenson for discovering the principle of the bonnet the same year. The modern lamps are safely locked so that a miner cannot unlock them in the mine but must take them to a safe place to be unlocked by a key or an electrical device. Most of them have a self-lighting device inside which insures greater safety to the men. Oil is the fuel mostly used. The light is much better in the modern lamp than in the older types since it has a glass envelope or chimney and the air enters near the base of the lamp.

The *electric cap lamp* has made its appearance in the mines during the last seven years and it gives promise of being very largely used because of its greater convenience and its efficiency in producing light.[1] It has one serious objection to the miner used to the other safety lamps, and that is the fact that it does not indicate the presence of harmful gases.

For open lights in non-gaseous mines acetylene generated from calcium carbide in contact with water produces a very efficient light and acetylene lights are very commonly used.

Mine Ventilation

Since a coal mine is certain to contain more or less foul air it is essential that it be well ventilated. There are two means of ventilating a mine: by a furnace and by a fan. A furnace may be used in the smaller mines which are not gaseous. It is built of brick at the foot of a shaft on the main airway, so as to create a strong upward

[1] Clark, H. H., Permissible electric lamps for mines. U. S. Bur. of Mines. Tech. Paper 75, 1914.

draft by convection currents generated by a fire which is kept burning all the time men are at work in the mine.

Mine fans are of many types. They may be constructed as the disc fan where the blades are arranged as they are on a windmill or as the centrifugal type in which the blades are normal to the plane of revolution. The fans are usually run so that they propel the air through the airways and to all the working places in the mine, but in some cases the fan may be run as an exhaust fan. It is considered necessary to so ventilate a mine that every man may have a minimum of 150 cubic feet of air per minute if the mine be non-gaseous and 200 cubic feet if it be gaseous. The velocity of the current of air in the mine workings is measured by an anemometer and the pressure by a water gage. If the anemometer reading were 1800 feet in three minutes and the size of the airway 6 feet by 10 feet the volume of air passing through would be found in the following way: $6 \times 10 \times \frac{1800}{3} = 36{,}000$ cubic feet per minute. Fans are as much as 35 feet in diameter and they are capable of delivering from a few thousand up to over 400,000 cubic feet of air per minute, depending upon the size and type of the fan, the rate at which it is run, and the mine resistance.

In ventilating a mine the foul air and explosive gases are driven out, but the fresh supply of oxygen tends to oxidize the coal and to set methane free, sometimes at a rapid rate. The air entering the mine becomes warmed and the presence of air with the increased temperature aids the absorption of moisture which is carried out with the air current, leaving the mine dry and in some cases dusty. The fine coal dust becomes distributed through the air and acts much the same as an explosive gas when ignited.[1] It has been shown that the dust is capable of producing tremendous explosions and it is particularly dangerous when mixed with gas as this increases the possibility of igniting the dust by lamps or blasts. The discovery of the ready explosibility of coal dust has aided greatly in avoiding many bad accidents. The danger of explosions may be greatly lessened by sprinkling the mine, and taking other precautions against trouble such as regulating the use of certain explosives, like black powder which generates a long flame on firing. There are certain explosives

[1] Rice, G. S., and others, Explosibility of coal dust. U. S. Geol. Survey, Bull. 20, 1911.

designated as *permissible explosives*[1] for coal mines and the use of these has aided in reducing accidents although they are not always the most suitable from the practical standpoint for producing the best type of coal for the market. Great strides have been made in recent years in the direction of greater protection for life and property in coal mining and the percentage of accidents has been greatly reduced. Mining has become a relatively safe occupation.

Mine Fires

Mine fires are one of the great causes of trouble in coal mines and they start by lamps firing gas, timbers or coal, or from blasts or spontaneous combustion. If they are taken in their incipient stages they can as a rule be put out although the safest practice is to take all precautions against letting them get started. When small they may be put out with water or a chemical extinguisher but when once well started they must be flooded or smothered out. In some cases it may be necessary to flood the whole mine, while in others dams of concrete, masonry or wood may be built and the spaces behind them flooded. In smothering a fire the mine shaft may have to be sealed up or a portion of the mine may be walled off and sealed so tightly that the fire dies out for want of oxygen. The sealing is done by walls of rock and clay, masonry or concrete. Sometimes a wooden wall is built, and clay, sand or other suitable material is filled in behind it. The waste or " slush " from a breaker or washery may in some cases be turned into the mine to seal up the fire. It is often extremely difficult to seal the area so tightly that no oxygen can enter and there are some fires which have burned for over half a century baffling all attempts to extinguish them. When sealed the area may retain its heat for years, and in some mines the fire which was supposed to be dead has broken out as soon as air was admitted. Great care must therefore be exercised in reopening a sealed mine or local area in a mine.

In some cases fires have been extinguished by mining out the seam around the fire, thus isolating it.

[1] Howell, S. P., Permissible explosives tested prior to Mar. 1, 1915. U. S. Bur. of Mines, Tech. Paper 100, 1915.

CHAPTER XI

THE PREPARATION AND USES OF COAL

Introduction

A glance at the statistics of distribution of coal mined in the United States shows the manner in which the coals of various ranks are divided for consumption.[1] In 1917 the distribution of approximately 80 million tons of Pennsylvania anthracite was as follows: nearly 51 million tons were of domestic sizes; 18 million tons of steam sizes; 6 million tons were used by railroads and over 4 million tons exported. For the same year about 366 million short tons of bituminous coal, mined and distributed in this country, were divided as follows:

Used at mines for steam and heat	12,117,159 tons
" in manufacture of beehive coke	52,246,612 "
" in manufacture of by-product coke	31,505,759 "
" in manufacture of coal gas	4,959,697 "
" by electrical utilities	31,692,722 "
" for domestic purposes	57,104,000 "
" for industrial purposes	176,365,939 "

In addition to the coal included in these figures about 153 million tons were used by the railroads and over 10 million tons were loaded at seaports for bunker purposes. Approximately 23 million tons were exported.

For industrial purposes and for the use of the railroads, the two largest items of consumption, a great variety of coals and grades of coal may be used. The same holds true for the electrical utilities, mine consumption and to a certain degree for domestic purposes. For certain types of industrial operations where special coals are required as, for example, in smithing, there were 255,000 tons used. For coking purposes certain limits may be placed on the grade and ranks of coal used, as low sulphur coals and coking varieties must be selected.

For domestic purposes the distinctions made lie more in the preparation of the coal for use than in the rank or grade of the coals, since all ranks from lignite to anthracite are extensively used and some of the coals are of very low grade. For gas manufacture particular types of fairly high volatile coals are best.

[1] U. S. Geol. Survey, Mineral Resources of the United States, 1917.

Preparation of Coal for Domestic Purposes

Anthracite. — On account of its high heating, low smoke-producing and long-burning qualities, and its freedom from dirt and dust, anthracite has long been a favorite domestic fuel. The operation of preparing it for market has become quite a highly developed mechanic art.

FIG. 101. — Slate pickers in an anthracite breaker. (Photo by courtesy of R. P. Hutchinson of the Bethlehem Fabricators Inc.)

There are two main objects in view in breaking and separating anthracite, one being that of getting it into uniform sizes so that it will readily burn in a grate and the other that of cleaning the coal by washing out the small particles of mineral matter and by removing the larger fragments of slate by hand or with mechanical separators. According to Sterling[1] the methods of preparation may be grouped under three classes, as follows: (1) Dry preparation, used for lump coal which comes from the mine dry and which readily

[1] Sterling, Paul, The preparation of anthracite. Trans. Amer. Inst. Min. Eng., Vol. 42, p. 264, 1912. Also Peele's Handbook for Mining Engineers, p. 1842.

separates from the waste rock; (2) Combination of dry and wet preparation employed when the run-of-mine contains a high percentage of impurities, perhaps up to 55 per cent, but also considerable lump coal which can be handled as in (1); (3) Wet preparation, when the run-of-mine is high in impurities and is discolored with iron or clay. This type of coal occurs near the surface and in disturbed zones in the mine.

The coal is taken from the mine mouth to the breaker in the mine cars or by conveyors, depending upon the relative position of the pit mouth and the top of the breaker. It is first passed over a sizing screen, sometimes known as a bull shaker, which sorts the lump from the smaller material, the former going to a picking table and the latter, which is often called the *mud-screen product*, moving along to be treated by the wet process, (Fig. 101). On the picking table pieces of rock are removed by hand. If coal and rock adhere the lumps are removed to a special table where they are broken by hand and the rock sent to the rock pile.

The cleaned lump goes to a pocket for shipment as *lump* or to the rolls to be broken, depending upon the demand for the different sizes. The rolls, which are furnished with teeth, break the coal into the sizes indicated by the following table:

TABLE SHOWING MARKET SIZES FOR ANTHRACITE AND SCREEN OPENINGS IN INCHES

Size of coal	Punched plate				Woven wire	
	Round		Square			
	Over	Through	Over	Through	Over	Through
Lump	$6\frac{1}{2}$	...	...	...	...	...
Steamboat	$4\frac{1}{2}$	$6\frac{1}{2}$	4	...	4	...
Broken	$3\frac{1}{4}$	$4\frac{1}{2}$	$2\frac{3}{4}$	4	$2\frac{3}{4}$	4
Egg	$2\frac{5}{16}$	$3\frac{1}{4}$	2	$2\frac{3}{4}$	2	$2\frac{3}{4}$
Stove	$1\frac{11}{16}$	$2\frac{5}{16}$	$1\frac{1}{2}$	2	$1\frac{1}{2}$	2
Chestnut	$1\frac{5}{16}$	$1\frac{11}{16}$	$\frac{13}{16}$	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{2}$
Pea	$\frac{5}{8}$	$1\frac{5}{16}$	$\frac{9}{16}$	$\frac{13}{16}$	$\frac{1}{2}$	$\frac{3}{4}$
Buckwheat	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{5}{16}$	$\frac{1}{2}$
Rice	$\frac{1}{4}$	$\frac{7}{16}$	...	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{16}$
Barley	$\frac{3}{32}$	$\frac{1}{4}$	...	...	...	$\frac{3}{16}$
Buckwheat No. 4	$\frac{3}{64}$	$\frac{3}{32}$	...	...	...	...

The percentages of each size allowable in the other sizes and the percentage of slate and bone allowable in the various sizes is shown in the following table:

TABLE OF STANDARDS OF PREPARATION IN PERCENTAGE

May contain	Broken	Egg	Stove	Nut	Pea	Buckwheat	Rice	Barley
Of slate......	1	2	2.5	4	8	10	15	15
Of bone......	2	2	4	5	5	...	...	...
Of next size larger......	...	5	5	10	5	8	8	8
Of next size smaller.....	20	50	50	15	15B 15R	15	25	...

After screening, the steamboat size is either sent to a pocket and shipped or sent to other rolls and further crushed, according to the condition of the market for various sizes. This process is continued until the whole operation is complete except that certain portions of the coal are put through the wet process to clean it if necessary. The course followed is clearly outlined by Ashmead[1] in the accompanying diagram, (Fig. 102).

The screens used in recent years are largely of the shaker type rather than the oscillating or gyratory screens. The advantages of the shaker type, according to Sterling, are: low first cost; ease with which it may be repaired and maintained; good sizing of smaller sizes; large capacity; ability to size material not over 150 pounds in weight in going to the picking room. The revolving screen does not vibrate the breaker as much as a shaker screen and it performs exact screening and sizing. It has smaller capacity, however, and requires more space than shaking screens of the same capacity. Only about one-eighth of the surface is in contact with the coal at one time. The first cost and maintenance are high.

There have been some recent developments in the use of jigs, especially of the plunger type, for separating the slate from the coal, and mechanical pickers are used a great deal for the same purpose in dry preparation. Where hand picking is done the moving table

[1] Ashmead, D. C., Modernized breaker with hand pickers, spirals, jigs and concentrators. Coal Age, Vol. 18, p. 585, 1920.

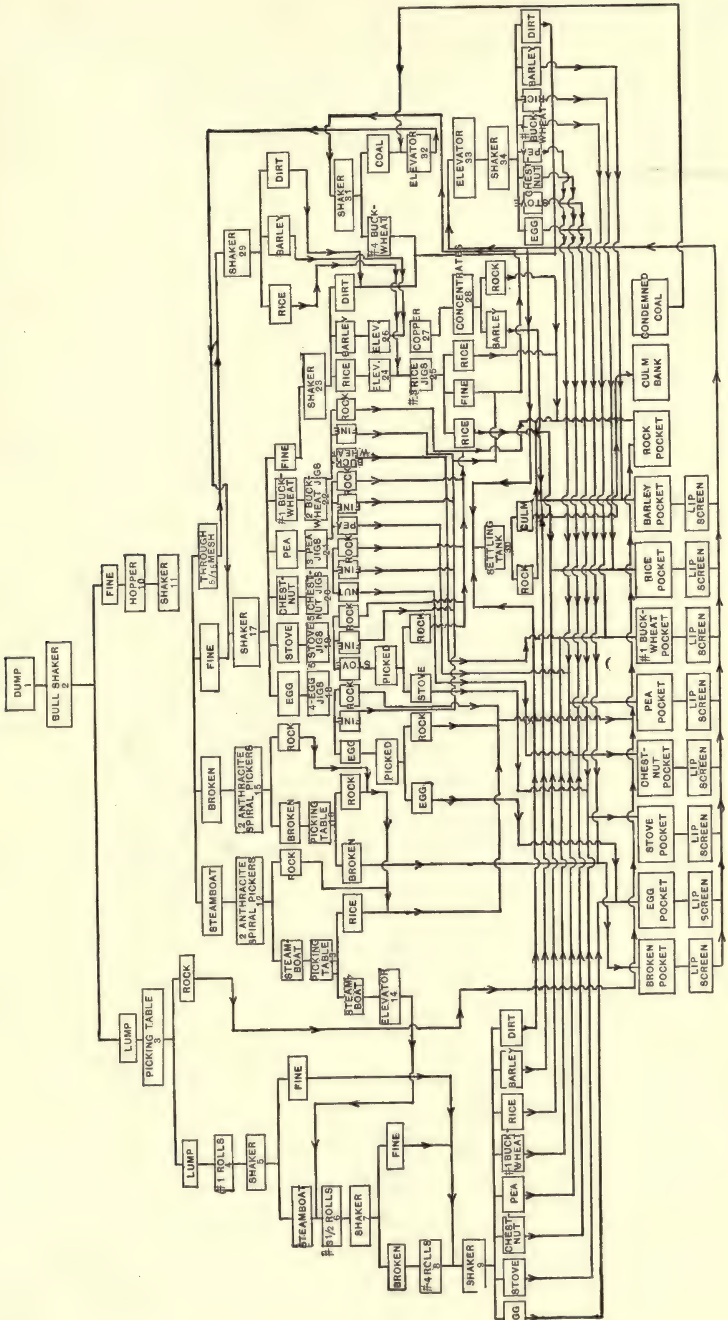


FIG. 102. — Flow sheet of the Alliance Breaker. (After Ashmead: Reproduced by courtesy of Coal Age.)

is found to be an advantage. In the automatic mechanical pickers the moving table is so arranged as to give it a pitch in two directions, first transverse to the table, and second along the center line. This requires the moving material to travel up hill and the coal is separated from the rock, owing to difference in specific gravity and friction

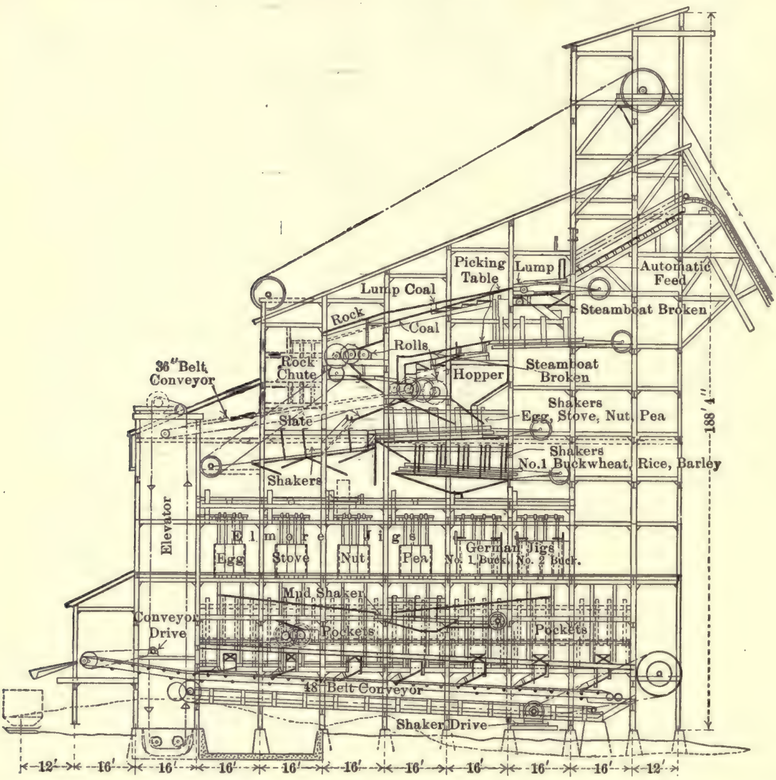


FIG. 103. — Cross-section of Alliance Breaker, showing loading method. (After Ashmead: Reproduced by courtesy of Coal Age.)

of the coal and slate on the table. The rock discharges at one point and the coal at another. With the increased efficiency of the cleaning equipment in the modern breakers it is now possible to save a much larger percentage of the coal than formerly and some of the culm banks can be reworked. Several large Pennsylvania anthracite companies have quite recently installed tables of the Deister-Overstrom type for washing the barley and smaller sizes of coal. There

seems to be a good future in the Anthracite region for the application of some of the devices so long used for ores, and adopted in some of the western fields for coal washing and separation.

Bituminous coal. — It is becoming more and more a custom to wash and size bituminous and semibituminous coal for domestic purposes. A cleaner coal and a coal which will burn better and stand storage better is produced in this way, and mining operations are aided because some labor in sorting coal and rock underground is saved. At many mines simple bar screens are used while at others modern shaker screens have been adopted. The coal is sorted into various sizes somewhat like anthracite but on a less perfectly developed plan. The state of Illinois has probably been the most advanced of the states of the Union in the systematic preparation of bituminous coal, and now only about 20 per cent of her output is sold as run-of-mine, the remainder being treated before shipment is made.[1] This remarkable development in washing and sizing operations in Illinois is partly due, however, to the fact that very little of the coal in the state is of coking quality. This is a type which does not need sizing for market, although it is customary to wash a great deal of coking coal to reduce the sulphur content. At mines where the coal is only passed over shaking screens and then sold, four sizes are commonly made; these are known by the following names:

Name	Size in inches	Per cent of total output
Lump	Over 6	15
Egg	Over 3½ through 6	19
No. 1 nut	Over 1¾ through 3½	16
No. 2 nut	Over 1 through 1¾	15
No. 3 nut	Over ¾ through 1	7
No. 4 nut	Over ¼ through ¾	7
No. 5 nut	Through ¼	21

The sizes for these different types vary somewhat in different fields. In some areas the lump sizes run through 8 grades of lump, from 8-inch lump to 1¼-inch lump and on down through chunk, egg, nut, pea and screenings. At some mines mechanical pickers, as well as men and boys, are employed and some companies wash the coal in addition

[1] Andros, S. O., Coal mining in Illinois. Illinois Coal Mining Investigations. Bull. 13, p. 202. Urbana, 1914.

to screening it. Washing tends to remove clay, slate and iron pyrite and this is quite an advantage for high sulphur coals for coking. An elaborate washery was put into operation at the United States Fuel Company's mine at Benton, Franklin County, Illinois in the fall of 1918.[1] It has been the hope of mining men that the greater part of the sulphur could be removed from coal by washing out the pyrite. Unfortunately, as previously pointed out in this text, it is impossible to wash out the sulphur in organic compounds, or the finely divided pyrite which is almost always present.

FIG. 104. — The Loree Breaker. (Photo by courtesy of R. P. Hutchinson, Bethlehem Fabricators, Inc.)

Storage

The storing of coal is a very important item in many industries. If it is not stored at times when it is plentiful and transportation facilities are good, plants may be tied up owing to break-downs in traffic or mining operations, resulting from storms, strikes or other causes. Another advantage in storing coal is that it distributes the demand more uniformly over the whole year and the peak load does

[1] Campbell, J. R., Mechanical separation of sulphur minerals from coal. Trans. Amer. Inst. Min. and Met. Eng., Vol. LXIII, p. 683, 1920. Also, Frazer, Thomas and Yancey, H. J., Some factors that affect the washability of a coal, p. 768.

not always fall in the winter when most coal is likely to be needed. According to Stoek the coal should be stored as near the place where it will be used as possible, although it is practical to store at the mines temporarily when the car supply is short. The main objections to storage of coal in large amounts are the breakage, the cost of rehandling, danger of fire from spontaneous combustion or other causes, the deterioration from weathering, the difficulty in securing adequate storage facilities in large cities where the coal may be stored near the plant in which it is to be used, and the possibility of a sudden and considerable drop in price.[1]

Spontaneous combustion. — The cause of spontaneous combustion is heating of the coal by oxidation and other agencies. Oxidation is continually going on in coal exposed to the air and there is a general impression that sulphur in the form of pyrite is responsible for much of the trouble. This is not the real cause although it may aid the chemical processes producing the heat. Sulphuric acid is developed to a certain extent in the weathering of iron pyrite and since it is such a strong oxidizing agent and generates so much heat on coming in contact with water the presence of pyrite will naturally have an effect on chemical action. It should be borne in mind, however, that the condition in which the pyrite occurs in the coal, whether finely divided, or coarsely crystallized, will have some influence on its rate of weathering and it is found that the rate varies greatly. Specimens of pyrite in a collection in a laboratory show great differences in the rate of alteration. Some will break down in the course of a few years while others will remain perfectly bright for an indefinite period.

In a recent paper some English writers[2] have claimed that *fusain*, (mother-of-coal or mineral charcoal) probably aids spontaneous combustion owing to the ease with which it crumbles to powder and takes fire. It smoulders in many cases without any evidence of flame. These writers have also found, as previously mentioned in this work, that mineral charcoal contains a higher percentage of ash and fixed carbon than the coal in which it occurs and that it is deleterious to the production of good coke. It seems possible to the writer, in view of

[1] Norris, R. V., The storage of anthracite. Trans. Amer. Inst. Min. Eng., Vol. XLII, p. 314, 1912. (Full discussion of systems of storage and handling.)

[2] Sinnatt, F. S., Stern, H., and Bayley, F., Does fusain cause mine and bin fires, spoil coke and aid explosions? Coal Age. Vol. 18, p. 384, 1920.

the great absorptive quality of wood charcoal, that mineral charcoal may have the power of occluding within its walls more gases than ordinary coal, and the presence of these gases would influence spontaneous combustion. This would be a very interesting field for investigation.

An investigation of the causes of spontaneous combustion with special reference to Illinois coals was carried out by Parr and Kressmann[1] and their conclusions were that the following factors entered into a consideration of the subject: (1) kind of coal with regard to its volatile matter; (2) purity of the coal; (3) presence of pyrite and other sulphur compounds; (4) temperature of the coal; (5) size of the fragments; (6) presence of occluded gases; (7) presence of moisture; (8) accessibility of oxygen; (9) pressure on the coal.

Regarding the kind of coal, it is found that those high, or fairly high, in volatile matter such as lignites, subbituminous, bituminous and semibituminous coal are the only ones which are likely to take fire. The anthracitic coals have too high an ignition temperature and they weather too slowly to take fire readily. According to Fayol lignite as fine dust takes fire at 150° C., gas coal at 200° C., coke at 250° C. and anthracite at 300° C. or above. He also found that coal absorbed oxygen about twice as fast as did pyrite.

The pure coals seem to oxidize more rapidly than those with more foreign matter. The effect of pyrite has already been described above. The size of the coal is an important factor as fine coal is a much more rapid absorbent of oxygen than lump and is dangerous in storage.

Occluded gases of an inflammable type, such as methane, no doubt favor spontaneous combustion, but to what extent is unknown.

Moisture under certain conditions aids the process since it influences the oxidation of pyrite and coal. Accessibility of oxygen is without question an important factor.

Pressure is believed to be an important factor in aiding the development of heat in coal, but to what extent and in what manner is not very fully understood.

Some of the remedies suggested for spontaneous combustion are: storage under water to eliminate oxidation; exclusion of fine coal by screening, or its regular distribution throughout the pile; keeping

[1] Parr, S. W., and Kressmann, F. W., The spontaneous combustion of coal, Illinois Experiment Station, Bull. 46, 1910.

the piles low, only a few feet high; keeping the coal away from external sources of heat such as boilers, pipes or the sun's rays; keeping it dry unless completely submerged; and elimination of high sulphur coals.

The deterioration of coal in storage. — From the researches of David White, previously mentioned, it is shown that oxygen in coal is practically equivalent to ash in its anti-calorific properties. The oxidation of coal therefore decreases its heating value. Regarding the deterioration in storage Parr[1] concludes that very little loss is suffered if the temperature is not allowed to rise above 180° F. as there is no appreciable evolution of CO_2 below 200° F. The loss per pound in heat value is due largely to an increase in weight per unit mass of coal on account of the absorption of oxygen, and Parr claims that the weathered coal gave just as satisfactory results in firing, if care were taken in controlling the fire, as the unweathered coal. In an earlier article Parr and Hamilton[2] present the following conclusions, in addition to those previously set forth: Submerged coal does not lose appreciably in heat value while outdoor exposure results in a loss in heating value of from 2 to 10 per cent. In some cases the losses appear to be complete at the end of five months. From the seventh to the ninth month the loss is not appreciable. Similar results were obtained by Porter and Ovitz[3] in experiments on Sheridan, Wyoming coal. They found that this coal lost 3 to 5.5 per cent of its heating value in about three years in storage, 70 to 80 per cent of the loss occurring within the first nine months. They also found that storage in air-tight bottom bins had a distinct advantage over covering the surface of the coal. The slacking of the coal is one of the important factors in weathering as it tends to destroy its firing qualities.

Briquetting[4]

The process of briquetting coal has developed considerably in recent years. It is applied to fuels which are dusty, such as peat, lig-

[1] Parr, S. W., Effects of storage upon the properties of coal. University of Illinois, Bull. No. 39, Vol. XIV, 1917.

[2] Parr, S. W., and Hamilton, N. D., The weathering of coal. University of Illinois, Bull. No. 33, 1907.

[3] Porter, H. C., and Ovitz, F. K., Deterioration in the heating value of coal during storage. U. S. Bur. of Mines, Bull. 136, 1917.

[4] Franke, G., A handbook of briquetting. Translated by F. Lantsberry, Charles Griffin and J. B. Lippincott, 1917.

nite, fine slack, and culm. It consists of compressing the powdered fuel into briquets or little bricks, using pitch as a bond to hold the particles together. The pressing is done at rather high temperatures.

In recent years much material from the culm banks of the anthracite region of Pennsylvania has been recovered, washed, dried, and briquetted. Many of the old culm piles contain the coal which is now sold as barley and buckwheat sizes. According to Dorrance,[1] at the Lehigh Coal and Navigation Company's plant the culm is loaded into gondolas of 100,000-pound capacity and taken to a track hopper at the briquetting plant. It is elevated to the drying plant and passed through Vulcan rotary kiln driers which are heated by gases from the furnace. It is screened on vibrating screens of Newago type, the material passing through the finest screen going to the refuse conveyor. The refuse from this and later screenings is sent to the mines at Summit Hill for slushing the mine fire burning there. Commercially-sized coal separated is sent to the drier building for feeding the furnaces. The material from the screens is sent to Damon air separators and the coal retained from them is sent to the bins and from there to the mixing-house. Solid coal-tar pitch is used as a binder and it is fed into rolls and cracked to " pea " and " dust" sizes. This is then elevated to the pitch-measuring apparatus which feeds the right proportion of pitch to a squirrel-cage pulverizer which in turn feeds it into a screw conveyor with a measured amount of culm material. These materials then pass to the briquetting-house and are sent through the mixers to the presses. In the mixers the material is heated with superheated steam to about 400° then cooled by a cooling fan and pressed into briquets. Briquets are used by the railroads and industrial concerns, while the little balls known as *boulets* are sold for domestic use since the larger size does not seem to burn as well in domestic heaters as the smaller balls.

Experiments have shown that a great number of binders may be used for briquetting, but some of them cost a prohibitive sum.[2] The nearness to the source of supply influences to quite a large extent the choice of the type of binder. The following binders have proven satisfactory and they are available in many localities: (1) Asphalt,

[1] Dorrance, Charles, Jr., Anthracite culm briquets. Trans. Amer. Inst. Min. Eng., Vol. XLII, p. 365, 1912.

[2] Mills, James E., Binders for coal briquets. U. S. Bur. of Mines, Bull. No. 24, 1911.

the heavy residuum from petroleum, costing about 45 to 60 cents per ton of briquets and used in proportion of 4 in 100. (2) Water-gas tar pitch costing 50 to 60 cents; 5 or 6 per cent is used. (3) Coal-tar pitch; 6.5 to 8 per cent is used per ton and the cost per ton of briquets runs 65 to 90 cents for binder. Other substances which might be used are starch, sulphite and magnesia.

The results of the tests made on briquets by the Bureau of Mines[1] indicate that there is considerable difficulty in burning them in domestic heaters where low temperatures prevail so much of the time, as the binder either tends to produce a deposit on the interior walls of the furnace and the pipes which clogs them, or it burns off too rapidly when the temperature rises quickly. The briquets ignite readily unless an inorganic binder is used or there is too much impurity in the slack from which they are made, and they produce a large amount of smoke if not properly fired. Their relative efficiency is high, they are clean and they weather very well. It is concluded, however, that there is no justification for briquetting lump coal and the main advantage in the process lies in consolidating coal which is in too fine a condition or is dusty. Lignite and fine coal, which does not coke may be profitably briquetted in many cases. Coking coals are more easily handled without briquetting than non-coking types since they are not readily lost by running through the grates. The average cost of briquetting a ton of fuel has been placed at about \$1.00 to \$1.80. Recent developments in the briquetting of partially devolatilized coal, or carbo-coal, indicate that there is probably a more promising future along that line than in the briquetting of the raw fuel.

Coals Used in Gas Manufacture

Producer gas. — Coals which are used in gas manufacture may vary greatly in quality and it is difficult to fix limits as to their properties. Fuels from peat to anthracite have been used for the manufacture of producer gas, which is coal gas diluted with air and often mixed with water-gas. They should, however, be comparatively low in sulphur and ash and the fusibility of the ash is an important factor. It should not be low. The size of the coal also has an impor-

[1] Wright, C. L., Fuel briquetting investigations. U. S. Bur. of Mines, Bull. 58, p. 191, 1913.

tant bearing as coarse run-of-mine is not good material. Egg and nut sizes are desirable and screenings may be used.[1]

Illuminating gas. — For illuminating gas a coal must be high in volatile matter so as to yield per short ton at least 10,000 cubic feet of gas at 60° F. and 30 inches mercury pressure, and the gas should test 16 to 18 standard candle power. Cannel coal has long been recognized as probably the most desirable coal for this purpose. The quality of the volatile constituents is important as well as the quantity. The coal should also yield a good proportion of coke. The sulphur must be low, not above $1\frac{1}{4}$ and preferably below 1 per cent, although coals have been used in some cases which run up to about 2 per cent. The sulphur unites with hydrogen to produce hydrogen sulphide H_2S and with carbon to produce carbon disulphide (CS_2). The former is an evil-smelling, poisonous gas and the latter under certain conditions has a horrible odor. Both of these gases burn to sulphur dioxide (SO_2) and this gas is not only suffocating and objectionable to man but it aids in tarnishing metal house-furnishings. The sulphur gases can be removed from the illuminating gas at a rather high and in many cases prohibitive cost.[2]

The following figures indicate the general chemical composition of coals which have been used and are well adapted for gas making:

	Cannel	*Bituminous gas coal*
Moisture	1.30– 4.50 per cent	1.00– 4.00 per cent
Volatile matter	30.00–39.00 "	28.00–37.00 "
Fixed carbon	50.00–60.00 "	54.00–61.00 "
Ash	2.20– 6.00 "	3.50–10.00 "
Sulphur	0.50– 1.05 "	0.80– 1.32 "
B.t.u.	13,000–14,500	13,200–14,600

Water gas. — Water gas is a commercial gas consisting very largely of carbon monoxide and hydrogen and it is made by dissociating steam into hydrogen and oxygen, thus permitting the latter to unite with carbon to form carbon monoxide (CO). Anthracite and coke have been most generally used for this purpose but non-coking bituminous coals might also be used.

[1] Brooks, G. S., and Nitchie, C. C., Gas producer practice in western zinc plants. Trans. Amer. Inst. Min. and Met. Eng., Vol. LXIII, p. 846, 1920.

[2] Odell, W. W., and Dunkley, W. A., Removal of sulphur from illuminating gas. Trans. Amer. Inst. Min. and Met. Eng., Vol. LIII, p. 660, 1920.

Smithing Coals

No very definite limits have been fixed for the quality of smithing coals. Semibituminous or "smokeless" coals have been generally used although anthracite and semianthracite coal have also been used. Some of the requirements for a first-class coal of this type are low sulphur, less than 1 per cent; high calorific value; low ash; and sufficient coking quality to seal over and retain the fire when articles are not being inserted or withdrawn.

Coals for Cement and Tile Burning

For a cement-burning coal the requirements are a high calorific value, 12,000 B.t.u. and upward, and a high volatile content. For burning brick and pottery, coals of high volatile content and non-coking qualities are desirable.

For burning porcelain and the finer grades of ceramic materials low sulphur is essential and low ash desirable. According to Parmelee[1] the English pottery practice requires a coal which comes near the following figures: Total sulphur, 1.20 per cent; sulphur in ash 0.11 per cent; and volatile sulphur 1.09 per cent. The practice in America is about as follows:

For Sanitary ware: Maximum 1.0 per cent; 0.5 per cent desirable.

For Sewer pipe: As high as 3.10 per cent has been used but 1.2 per cent should be the maximum and 1.1 per cent is about present run.

Terra Cotta: 1.0 per cent is approximate and 0.5 per cent is basis of contract.

Pottery: 1.0 per cent contract basis and 1.5 per cent probable content.

Enameled brick: 1.3 per cent maximum.

Powdered Fuel

Powdered fuel must be ground exceedingly fine and then be blown into the furnaces with a supply of air adequate to completely consume it. For ordinary steam purposes the sulphur and a reasonable amount of ash do not greatly affect the qualifications, but for use in the steel plants the sulphur and ash must be low. The same rules should govern the proportions of sulphur in such fuel as in coke. The

[1] Parmelee, C. W., Effect of sulphur in coal used in ceramic industries. Trans. Amer. Inst. Min. and Met. Eng., Vol. LXIII, p. 727, 1920.

volatile matter should be over 30 per cent and the greater the proportion of combustible gas in the volatile matter the better the quality, other things being equal.

There is an interesting new development in the use of coal as a *colloidal fuel*.[1] The use of this type of fuel is largely in the experimental stage but there may be a large future for it. The colloidal fuel in which coal has been concerned is very finely powdered coal suspended in fuel oil. Several types of coal have been used and the calorific power developed has been high. There seems to be a possibility of not only suspending the fine coal in the liquid as a mechanical mixture but also of dissolving certain parts of it so that it actually goes into a liquid condition.

Steam Coals

Coals used in the production of steam include especially those used on ships, in locomotives and under stationary boilers and they embrace a wide range in ranks and grades. The ideal steaming coal is one combining high calorific power with small smoke- and clinker-producing, as well as fairly long-burning qualities. It should also be sufficiently high in volatile matter to permit a rapid response to stimulated firing, as a fireman on a locomotive, for example, may need a fire which responds rather quickly when heavy grades are approached. The coal must also be capable of standing storage, especially when employed for bunkering purposes. The presence of sulphur will influence its qualities for storing as well as the clinkering of the ash since sulphur, especially in the form of mineral sulphides, seems to show a marked influence in lowering the temperature of fusion of the ash if present in quantities over about 2 per cent. The character of the ash and the methods of firing will also influence the results to a marked degree. The iron of the pyrite unites with other elements and produces more fusible compounds. The sulphur compounds also break up and form new compounds some of which corrode the furnaces.

Semibituminous, or so-called "smokeless," coal has long been recognized in America and abroad as the finest type of steam coal.

[1] Sheppard, S. E., Colloidal fuels, their preparation and properties. Jour. of Ind. and Eng. Chem. Vol. 13, p. 37, 1921.

It has the highest calorific value of any coal and it contains sufficient volatile matter to make it ignite a little more readily than anthracite.

Some of the best steam coals in America are the semibituminous coals of Virginia, West Virginia, Maryland, Central Pennsylvania, Arkansas, and Alberta, Canada. The steam coals of South Wales have long been famous.

Analyses showing the limits in composition of some of the well-known types of semibituminous coals in the United States are as follows:[1]

	Arkansas	Maryland	Pennsylvania	West Virginia
Moisture	0.85– 3.50	0.38– 3.40	0.57– 4.50	0.30– 3.40
Volatile matter	11.40–16.60	15.40–27.00	15.80–27.20	13.10–22.00
Fixed carbon	72.00–77.00	57.20–76.60	64.30–78.00	71.90–79.00
Ash	7.40–12.00	4.20–18.50	2.40–12.20	2.00–11.20
Sulphur	1.30– 2.80	0.80– 4.70	0.50– 2.10	0.50– 2.50
B.t.u.	13,200–14,650	12,760–14,900	13,400–14,650	14,000–14,920

An analysis of high-grade Pocahontas coal would be illustrated by the following figures: Moisture, 1.31; Volatile matter, 16.30; Fixed carbon, 77.06; Ash, 5.33; Sulphur, 0.67; and B.t.u. 14,746.

Coking

The coking of coals for the purpose of securing metallurgical coke is a process which has long been in vogue and it has attained a place of great importance in our industrial operations. There are, however, some new phases of this process which bid fair to become of much more widespread interest than that of simply securing metallurgical coke. They are the saving of the volatile products from the coal and the production of solid fuels which will be better suited than coal for domestic use and for some industrial purposes.

Coke. — Coke is the hard residue obtained from heating coals in the absence of air. It has a dull to submetallic luster, is dark gray to silvery gray in color and is very porous, or vesicular. There is sometimes a great variation in the strength of coke made from the same coal seam. Some of it will support the largest blast furnace

[1] Analyses from the Coal Catalog, Zern, E. N., Editor, Keystone Publishing Co., Pittsburgh, 1918. This work contains analyses of practically all coal seams in the country.

charges while other portions will not. The percentage of coke which may be derived from coal varies from about 50 to 80 per cent, but a profitable coking coal should yield on the average at least from 65 to 70 per cent coke.

Coking coals. — The question of what physical and chemical properties determine the quality of a coking or caking coal has not been fully decided. It is known that certain portions of a coking coal are soluble in such solvents as aniline, phenol, or pyridine, and that these soluble constituents constitute the better coking ingredients. As previously stated in the discussion on *coking coal* it has been found by Pishel that coking coals tend to adhere to the sides of an agate mortar when rubbed with a pestle while non-coking coals do not. White also shows that there is some relation between the oxygen and hydrogen ratio and the coking quality. When $\frac{H}{O} > 58$ the coal generally cokes; when $\frac{H}{O} > 55 < 58$ the coal may coke; when $\frac{H}{O} > 50 < 55$ the coal is not likely to coke satisfactorily. Exceptions must be made for weathered coals. A test which is often used, especially in Europe, to determine the coking qualities of a coal consists in mixing the powdered coal with sand and heating the mixture. The coking quality is judged from the ability of the coal to cause the sand grains to stick together in a coherent mass, and the greater the amount of sand the coal can cement the better its coking qualities. The relative qualities of the various coals are fixed by a scale made for that purpose. All coals leave a residue but in many cases it is powdery and incoherent and of no value unless it is briquetted. It is assumed that a good coking coal should run over 30 per cent volatile matter and have not more than $1\frac{1}{2}$ per cent sulphur and 0.02 per cent phosphorous.

The requirements of the American Society for Testing Materials, for standard foundry coke are that the dry coke shall not exceed the following limits in chemical composition:

Volatile matter......	not over	2.0 per cent
Fixed carbon	not under	86.0 "
Ash................	not over	12.0 "
Sulphur............	not over	1.0 "

Sulphur in coke. — Owing to the fact that the mineral constituents in the coal mostly enter the coke with the ash some of the sulphur

is carried into the coke. The statement is frequently made that approximately one-half of the sulphur of the coal is driven off and the other half remains in the coke. This assumption has been largely verified by the recent work of Powell[1] although some factors not always considered must be taken into consideration in dealing with this subject. Sulphur in the coal may be in three forms: mineral sulphides, as pyrite and related minerals; organic sulphur, in some undetermined form; and sulphates, in small amounts. The organic type occurs in quantities ranging from 0.5 to 2.0 per cent and the quantity is nearly uniform for a seam or locality. Apparently this uniformity is due to the nature of the plants which grew in that locality and to the bacteriological and other conditions existing at that time. Pure pyrite is completely decomposed at 1000° C. and the resulting products are ferrous sulphide and free sulphur, the latter uniting with hydrogen if this element be available to form hydrogen sulphide. A negligible amount of the sulphur remains in the ferrous sulphide in the form of a solid solution known as pyrrhotite, or magnetic sulphide of iron. The sulphur is thus practically equally divided between the volatile and residual constituents. From his tests on the carbonization of coals Powell concludes as follows: (1) At 300° C. decomposition of the pyrite begins with the formation of pyrrhotite and hydrogen sulphide. The reaction is complete at 600° C. and reaches its maximum between 400 and 500° C. (2) At 600° C. the reduction of sulphates to sulphides is complete. (3) Decomposition of $\frac{1}{4}$ to $\frac{1}{3}$ of the organic sulphur takes place to form hydrogen sulphide. Most of this reaction occurs below 500° C. (4) A small part of the organic sulphur decomposes to form volatile, organic sulphur compounds most of which enter the tar. This reaction takes place chiefly at the lower temperatures of the process. (5) A portion of the pyrrhotite disappears and the sulphur apparently enters into combination with carbon. This reaction is most active at 500° or more. Between 400 and 500° C. the organic sulphur not accounted for above undergoes decided changes and ceases to resemble the original sulphur in the coal. It appears therefore that the percentage of sulphur originally in the coal rather than the form of the sulphur will be the prevailing factor to be considered. Some carbon bisul-

[1] Powell, A. R., Some factors affecting the sulphur content of coke and gas in the carbonization of coal. Jour. Ind. and Eng. Chem. Vol. 13, p. 33, 1921.

phide is formed from hydrogen sulphide where it passes over red-hot coke. If hydrogen is passed through coke at a temperature above 600° C. a marked evolution of hydrogen sulphide occurs although the coke had ceased to evolve hydrogen sulphide at about 600° C. The effect of the hydrogen is to aid the decomposition of iron pyrite at a temperature below 500° C. and the decomposition of organic sulphur compounds at temperatures above 500° C. Hydrogen over a coke containing 1.2 per cent sulphur was saturated, when it contained about 0.25 pounds of sulphur per 1000 cubic feet with the coke at 900° C. Hydrogen can therefore scarcely be regarded as an agent which could be profitably employed to remove sulphur from coke.

Apparently the gases given off in the coking process play an active part in removing the sulphur from the coke if they can be relieved of their load of sulphur and returned over the coke. Less sulphur was found in the by-product coke when the gases were returned in contact with the coking mass than in the coke where the gases were drawn entirely away from the mass. One may predict therefore, that some method may be devised to eliminate to quite an extent the sulphur in the coke.

Beehive coking. — The earliest forms of beehive ovens, which get their names from their shape, were built of clay but the modern ovens are standardized in size and form and are constructed of masonry, brick and tile. Fire brick is used for lining and the space between the lining and outside walls is filled with waste brick and other material to prevent, as far as possible, the loss of heat to the exterior. The ovens, which are usually 12.5 feet long by about 7 feet high internally, are arranged in a double row and connected with a common flue, the opening to which is controlled by a damper. In some places the hot waste gases are used for producing steam in the power plant or for heating purposes. The cost of an individual oven in normal times runs from about $450.00 to $500.00.

The oven is started at first with a wood fire and coal is added gradually for from two to four days to prevent cracking the brickwork. A small charge may then be added and the front door bricked up, leaving holes for air. The burning of this charge, which does not give good coke, is performed to heat the oven and the resulting material may be rejected or used to heat other ovens. When the oven is hot a charge is loaded in after the front door has been bricked up

about two-thirds of the distance to the top. The charge for a standard oven is about 5 tons. The proportionate swelling of the coal on heating varies with different coals.

In many places the coal is crushed to about $\frac{1}{4}$ mesh before charging, unless it be finely divided when it comes from the mine. The charge is carefully leveled with a leveling bar and the door bricked and

FIG. 105. — Beehive ovens at the Isabella plant of the Hecla Coal and Coke Co. (By courtesy of the Hillman Coal and Coke Company, Pittsburgh, Pa.)

sealed up within about $1\frac{1}{2}$ inches of the top, or far enough to admit just about the right amount of air to burn the gas above the charge. During the latter part of the process the oven is sealed tightly to prevent entrance of air, which causes loss of coke by combustion. The length of time the coke is burned depends upon the purpose to which it is to be put. The best foundry coke is burned for about seventy hours but about forty-five hours is the time many ovens are run for other types of coke.

When the charge is burned the "coke-puller" places a sort of iron sprinkler with comparatively large orifices, in the oven and *quenches* the coke, applying upwards of 1000 gallons of water to each oven. Care should be exercised so that the lower part of the oven will not be so cooled with excess water that it will not start the fresh charge when it is added. The coke is then drawn either by hand or with a drawing machine and is loaded with a fork so that the fines are separated.

The Coppee type of oven. — In an effort to exclude all direct access of air to the coking chamber Coppee introduced a retort type of oven in 1861.[1] The oven consists of narrow rectangular chambers about 30 feet long and 3½ feet high. They are built with a slight taper towards one end to lessen the friction of discharging. The ovens are charged at the top and the gases pass into a series of vertical flues into which enough air is admitted to permit the combustion of the gases. The hot gases move downwards into a sole flue and after passing under the whole length of the oven they return to a chimney by the sole flue of the adjoining oven. They pass over boilers to utilize the heat and then up a chimney. The oven is discharged by a pusher and the coke is quenched outside the oven. The advantages claimed for this type over the ordinary beehive oven are: greater yield because of exclusion of air from the coking chamber; shorter coking period, because hot gases are utilized; saving in oven heat, because of external quenching and use of mechanical appliances.

By-product coking. — The beehive oven has long been recognized as an extremely wasteful apparatus and the time is rapidly coming when it will be entirely superseded by the by-product type which will save all of the volatile constituents as well as the coke. It was thought for a long time by metallurgists that the coke made in by-product ovens was inferior to that made in beehive ovens, but the by-product coke has become quite popular and it has been found that in regular operation the consumption of by-product coke per ton of pig iron manufactured is from 100 to 300 pounds less than of beehive coke, in the same operation.[2] Further, the energy used in coking a ton of

[1] Byrom, T. H., and Christopher, J. E., Modern coking practice. Crosby, Lockwood and Son, 1910.

[2] Sperr, F. W. Jr., and Bird, E. H Bv-product coking. Jour. Ind. and Eng. Chem., Vol. 13, p. 26, 1921.

coal in a beehive oven is 9,388,000 B.t.u., the equivalent of 671 pounds of coal, or 33.5 per cent of the heating value of the coal, while in the same operation in a by-product oven the energy expended is 2,408,000 B.t.u., the equivalent of 172 pounds of coal, or 8.6 per cent of the heating value of the coal.

As pointed out above it is apparent that it is possible to produce lower sulphur coke from a given coal in the by-product than in the beehive oven. Coals running as high as 35 per cent volatile matter have been used in a by-product oven although it is customary to mix high volatile coals with lower volatile types and thus produce a suitable mixture. Kreisinger gives the following figures as representa-

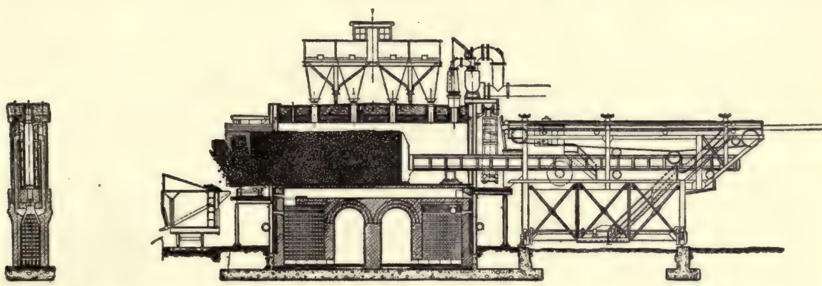


FIG. 106. — Semet-Solvay coke pusher and cross-section of a regenerative oven. (By courtesy of the Semet-Solvay Co.)

tive of the composition of the coal from a number of mines used in making by-product coke: Moisture, 2.77 per cent; Volatile matter, 34.17; Fixed carbon, 56.94; Ash, 8.99; and Sulphur, 1.37. The analysis of the coke runs: Moisture, 0.79 per cent; Volatile matter, 2.80; Fixed carbon, 79.29; and Ash, 17.14. In general, coals used run from 26 to 35 per cent volatile matter. The sulphur must not exceed 1 per cent in first-grade coke, and the ash in the coal must be less than 8 per cent if used for manufacture of first-grade coke. For second-grade coke sulphur has been placed at 1.20 per cent as a maximum and ash in the coal at 10 per cent.

In 1893 the production of beehive coke in the United States was 9,464,730 short tons and of by-product coke 12,850 tons. In 1919 the production of beehive coke was 19,650,000 short tons and of by-product 25,171,000 tons,[1] showing that the supremacy of the

[1] Mineral Industry, p. 116, 1919.

beehive is rapidly waning. The by-products recovered for the year 1919 amounted to 668,200,000 pounds ammonium sulphate or its equivalent; 251,000,000 gallons of tar; 84,800,000 gallons of crude light oil and 367,700,000,000 cubic feet of gas.

The cost of installing a large by-product plant has been one of the obstacles in the way of a more rapid introduction of the ovens although they are becoming very numerous, many of them being established

FIG. 107. — Semet-Solvay plant constructed for the Chattanooga Coke and Gas Co. (By courtesy of the Semet-Solvay Co.)

in connection with the large metallurgical plants where the gas and tar are utilized for fuel. They are also built near cities where the gas can be utilized. The cost of some of the large plants runs from several hundred thousand to several million dollars.

The main principle of the by-product oven is the heating of a chamber full of coal, which is connected with a system of condensers and stills. It is distinctly a distillation process. There are several types of ovens, such as the Semet-Solvay, Koppers, Otto-Hoffman, Otto-Hilgenstock, Coppee, Roberts, Willputte and Klonne. Of these the Semet-Solvay and Koppers are the most common in America

with the Otto type next. The Koppers has vertical and the Semet-Solvay horizontal flues (Figs. 106 and 108). The modern ovens are of the regenerative type, that is, they use the waste heat, and live gas from the ovens to heat the regenerators which in turn heat the air drawn through them on its way to aid combustion in the flues, where the gas from the ovens is used to maintain heat. The direction of the current of gas or air is reversed about every half hour and in that way the regenerators are kept hot.

The ovens are arranged in *batteries* and each oven is a steel chamber surrounded by flues and lined with silica brick. The batteries vary in size, but 60 ovens make a battery in the large plants and the largest plants have 640 or more ovens. An oven of a large type is about 30 to 36 feet long by 10 feet high while the smaller types are only about 6 feet high. The coke is pushed out of the oven by a pusher and taken in cars to a quenching bath. As a rule about 8 tons of crushed coal are fed into an oven with a charging machine and it is fired for from seventeen to twenty-four hours, depending upon requirements. A large plant will handle between 700 and 800 tons of coal per hour.

Derivatives from by-product ovens. — The process of separating the various by-products from one another is very complicated and a vast number of derivatives are obtainable. (See chart, Fig. 5.) The volatile constituents are drawn off the ovens and through condensers and scrubbers by means of powerful exhausters. The tar is practically all eliminated from the other constituents by the reduction of temperature. The remaining tar is finally eliminated by the impinging method employed in *tar extractors* of the impact type in which the tar and other constituents are drawn against a combination of perforated and plain plates, the tar adhering while the more fluid constituents pass on. The ammonia is removed by scrubbers in which water absorbs the gas, and the oils are distilled (Fig. 108).

The common products of the ovens are coke, gas, tar and ammonia liquor. The coke is used for metallurgical, foundry and heating purposes, and the fines from the coke, known as *coke breeze* are burned under boilers in power plants or other steam plants. The gas may be scrubbed and used for illuminating purposes, or it may be used for heating. In some cases it has been used in internal combustion engines. The tar is used to a large extent as fuel, in road making,

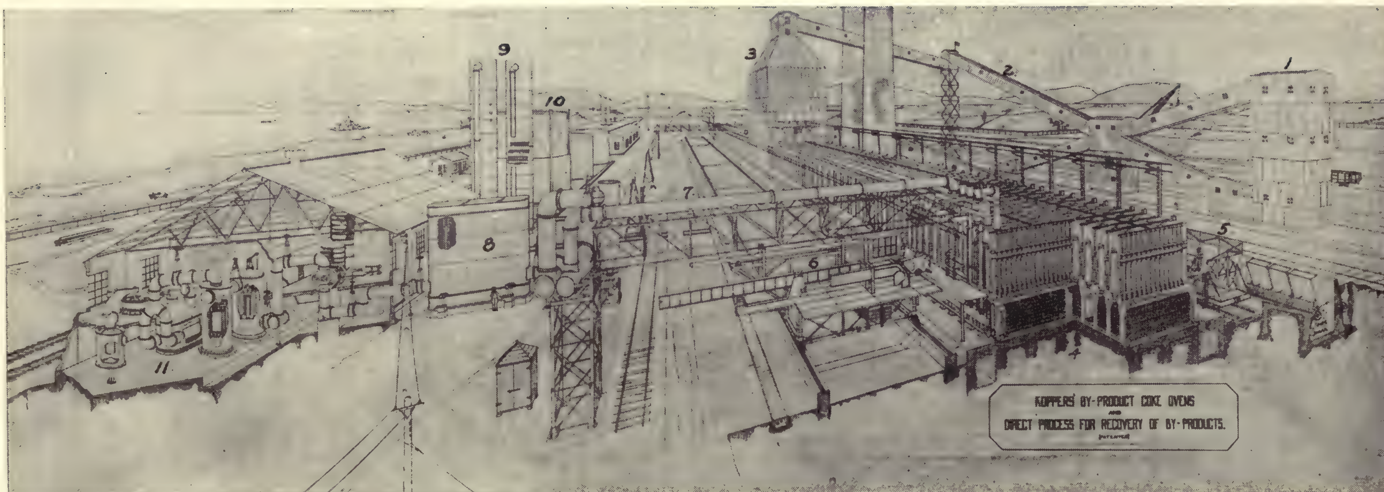


Fig. 108. — A Koppers by-product coke plant. — 1, Crusher and mixing building; 2, Elevator; 3, Coal bins; 4, Ovens; 5, Quenching car; 6, Coke pusher; 7, Gas suction main; 8, Primary cooler; 9, Final cooler and benzol washer; 10, Gas holder; 11, Tar extractors, etc. (By courtesy of the Koppers Company.)

in waterproofing, in paints and for other purposes. By heating it between 170° C. and 360° C. a number of derivatives may be obtained which include heavy and light oils, creosote, pitch and other constituents. The most important of the oils are benzol and toluol, the former of which on distillation gives a number of light oils such as gasoline and naphtha. The coal-tar dyes and numerous other valuable constituents are derived by further distillation. The ammonia liquor is used chiefly for the extraction of sulphate of ammonia by treatment with sulphuric acid. The sulphate has extensive application in the chemical industries and in the manufacture of fertilizers.

The total value of the by-products from coke produced in the United States in 1916 was placed at $61,931,595 of which nearly 25 million dollars were obtained from the benzol and toluol. The value of the coke for the same year was $75,373,070.

The following figures show the amount of coal used for coking in the United States, the average yield of coke per cent from the coal, and the value of the coke, for the years 1915, 1916 and 1917:

	Coal for ovens	Average percentage yield	Value at ovens
	Beehive ovens		
1915	42,278,516	65.1	$ 56,945,543
1916	55,084,958	64.4	95,468,127
1917	52,246,612	63.5	159,599,864
	By-product ovens		
1915	19,554,382	72.0	48,558,325
1916	26,524,502	71.9	75,373,070
1917	31,505,759	71.2	83,752,371

Of the states of the Union, Pennsylvania far surpasses all others in production, her output being about 60 per cent of that for the country.

Manufacture of coke for domestic fuel. — Some coke is now used for domestic and steaming purposes, but 80 to 90 per cent of all coke produced is used in the metallurgical industry. There has been a strong desire in recent years among men interested in fuels to find a fuel for domestic purposes with properties somewhere between those of coal and coke.

A process has recently been tried out at Syracuse, New York, by Donald Markle, for one of the Pennsylvania anthracite companies with the object of briquetting and coking anthracite fines. Culm is

washed, the coal crushed, cemented with 14 to 25 per cent of pitch to form briquets and then burned in an oven. The product is known as *anthrocoal* and it is claimed that the experiments tried have produced a very satisfactory domestic fuel which on test was 20 per cent more efficient in a kitchen range than chestnut coal.

The development of the process for carbonization of coal at low temperatures has led to the production of *carbocoal*, a fuel containing a little more of the volatile combustible constituents of the coal, than that contained in ordinary coke, the ratio being about 3 to 1. It, therefore, approaches anthracite as a fuel in burning longer, in being cleaner, in producing less smoke and in standing storage better than bituminous or other coals which lie below anthracite in fixed carbon. It has been shown by experiment in Canada[1] that lignite may be satisfactorily carbonized and the coked material, which is too powdery to be used in that condition, briquetted. From a ton of 2000 pounds of this lignite 3150 cubic feet of gas, 10.2 pounds of ammonium sulphate, 5.3 imperial gallons of tar, and 910 pounds of carbonized residue were obtained. The coal used contains 31.8 per cent moisture. The carbonized products had an available heating value 75 per cent above that of the original coal.

Bituminous coal has been treated very satisfactorily by carbonizing it at low temperature and briquetting the coke formed. From coals running over 32 per cent volatile matter where carbonized at 850° to 950° F. the following constituents have been obtained:[2]

By-products per ton of coal

Dry tar	34 gallons
Gas	8457 cubic feet
Ammonium sulphate	21 pounds
Light oil from gas	1.87 gallons
Other tar oils	19.3 gallons
Pitch, per cent of tar	43

The average analysis of the briquets made from the residue is as follows:

Volatile matter	3.8	per cent
Fixed carbon	85.1	"
Ash	11.1	"

[1] Stansfield, Edgar, Carbonization of Canadian lignite. Jour. Ind. and Eng. Chem., Vol. 13, p. 17, 1921.

[2] Curtis, H. A., The commercial realization of the low-temperature carbonization of coal. Jour. Ind. and Eng. Chem., Vol. 13, p. 23, 1921.

The production of such fuels has been put on a commercial basis within the last couple of years. A description of a plant at Clinchfield, Virginia, capable of treating 500 tons a day has been published by Eshereck.[1] In this plant there are 24 primary, low-temperature, and 10 high-temperature retorts. The primary retorts are arranged in four batteries and the crushed coal is fed into them from overhead bins. The semi-carbocoal is taken from these retorts, which are continually in operation and carried to storage bins in the briquetting plant. It is then ground, mixed with pitch, fluxed and briquetted on heavy roll presses. The briquets are carried on a long conveyor and then by a steel charging car to the secondary retorts. The finished briquets are dumped from the secondary retorts, which are inclined, and later quenched.

The by-products are carried through the same general process of condensing, scrubbing and distilling as in the other by-product processes described above. The process outlined is known as the *Smith Process*. It is found that the yield of carbocoal runs from 65 to 72 per cent of the coal used, depending upon the character of the coal, and on account of the low temperatures at which the primary retorts are heated there is a much greater yield of tar oils than in ordinary by-product operations. In some cases it is over seven times as great. There is practically no production of pitch, but the other constituents are similar in quantity to those derived from a by-product coke oven.

It seems very probable that this method of producing fuel will have a rapid development and that in the future practically all of our fuels will be treated in some such manner. It is also probable that some of the liquid by-products obtained from this process will be used in our homes as domestic fuel.

[1] Eshereck, George, Jr., Prospect that soon no coal will be used without preliminary devolatilization. Coal Age, Vol. 18, p. 327, 1920.

CHAPTER XII

THE GEOLOGIC AND GEOGRAPHIC DISTRIBUTION OF COAL

From a geological standpoint coal is distributed through the various formations from the Upper Devonian to the Pleistocene although the latter contains only low-grade coal and the former a very limited quantity. In the later Pleistocene and the Recent rocks large beds of peat not yet changed to coal are found in many countries.

The earliest coal deposits known are in the Upper Devonian in northern Russia and on Buren Island, Norway, and they are coincident with the first great development of land plants on the earth. Between the Devonian and Pleistocene there is not a geological system without at least some coal somewhere on the globe. Certain systems, however, carry the bulk of the valuable coal. Taking the earth as a whole the Carboniferous is the most important for high-grade coal while the Tertiary contains most of the lignite. The Mississippian, or Lower Carboniferous, as it is known outside of the United States, carries valuable coal in Virginia, Scotland, Spitzbergen, Russia, Corea and Manchuria. The Permian is very important in the Southern Hemisphere, particularly in Australia, India and Africa, and this system also carries some coal in Europe, the United States and eastern Asia. The Triassic is a prominent coal-bearing system outside of America as it contains the coal of Tasmania, some in Queensland and New South Wales, Australia, considerable in Hungary, Austria, Japan, China and South Africa and a small field in North Carolina and Virginia, in the eastern United States. The Jurassic is not important in America outside of Alaska and small areas in the Yukon but it is of great importance in China and Corea, and it is also coal-bearing in New Zealand and Austria. The Upper Cretaceous is one of the great coal-bearing periods in the earth's history especially in western North America and Central Europe, while the Lower Cretaceous, or Comanchean of some of the United States geologists, except in its

earlier formations, is probably the most barren of coal of all the systems from the Lower Carboniferous onward. It carries good coal in western Canada and in limited areas in the western states, a little in South Australia, and low grade bituminous coal in Spain. The abundance of coal in the Upper Cretaceous and Tertiary, following its scarcity in the Lower Cretaceous repeats the conditions existing in the Lower and Upper Carboniferous. The Lower Carboniferous and the Lower Cretaceous were periods of extension of the sea over the continents, except in the earlier stages of the Lower Cretaceous when many lakes and swamps existed, while it gradually withdrew during the following periods leaving great flat areas covered with swamps, as in the case of our coastal plains of the present day. Extension of the sea and marine deposition or, on the other hand, very high lands with rapid erosion do not go together with coal formation, but the gradual restriction of the sea and the formation of coal work together harmoniously.

The period of coal formation begun in the Upper Cretaceous continued into the Tertiary and most of the lignite of the world was formed in that period. Every continent contains some coal of this age and America and Europe have very large supplies. There is some good anthracite and bituminous coal of Tertiary age but most of the coal outside of the mountain regions is of the lignite type because it has not been changed to a higher form by heat or pressure or by these two agencies combined.

As to the occurrence of coal in rocks older than the Upper Devonian, the question is often asked why coal should not exist in these older formations. The only explanation is that the land plants had not reached a stage in their evolution which made them sufficiently abundant and widely distributed to form extensive deposits of coal. Deposits of vegetal matter were made in earlier formations, even back in the pre-Cambrian, as shown by beds of black shales and deposits of graphite, but these were of quite limited extent and apparently made from aquatic plants. It is also true that from the close of the pre-Cambrian until the Carboniferous not only the American continent but some of the others as well were largely covered with the sea and marine deposits were the main types being formed. It requires proper topographic conditions as well as an abundance of land plants to produce coal.

TABLE OF GEOLOGICAL FORMATIONS USED IN AMERICA, EUROPE AND AUSTRALIA WITH SPECIAL REFERENCE TO COAL-BEARING SERIES

		America	Great Britain	France	Germany	Australia
Cenozoic	Quaternary	Recent Pleistocene	Recent Pleistocene	Recent Pleistocene	Alluvium Pleistocene or Diluvium	Recent Pleistocene
	Tertiary	Pliocene Miocene Oligocene Eocene	Pliocene Miocene Oligocene Eocene	Pliocene Miocene Oligocene Eocene	Pliocan Miocan Oligocan Paleocan	Pliocene Miocene Oligocene Eocene
Mesozoic		Cretaceous (Upper) (1) Laramie (2) Montana (3) Colorado (4) Dakota	Cretaceous (Upper) (1) Upper Chalk (2) Lower Chalk (3) Marls (4) Upper Green-sand (5) Gault	Cretacique Neocretacique	Kreide Ober Kreide	Cretaceous (Upper)
		Comanchean or Lower Cretaceous	Cretaceous (Lower) (1) Lower Green-sand (2) Wealden	Eocretacique	Unter-Kreide (1) Gault (2) Weald	Cretaceous (Lower)
		Jurassic (1) Upper (2) Middle (3) Lower	Jurassic (1) Oolite (2) Lias	Jurassique (1) Neojurassique (2) Mesojurassique (3) Eojurassique	Jura (1) Malm (2) Dogger (2) Lias	Jurassic
		Triassic (Newark series)	Triassic (1) Rhaetic (2) Keuper (3) Bunter	Triassique	Trias (1) Rhaetic (2) Keuper (3) Muschel-kalk (4) Bunter	Triassic

TABLE OF GEOLOGICAL FORMATIONS (*Continued*)

	America	Great Britain	France	Germany	Australia
Palaeozoic	Permian (Dunkard) Upper Barren Measures	Permian or Dyas	Permien (*a*) Thuringien (*b*) Saxonien (*c*) Atunien	Perm (*a*) Zechstein (*b*) Rothliegende	Permo-Carboniferous (*a*) Igneous series (*b*) Upper or Newcastle Coal Measures (*c*) Dempsey series (*d*) Middle Coal Measures (*e*) Upper Marine Series (*f*) Lower or Greta Coal Measures (*g*) Lower Marine Series
	Carboniferous	Carboniferous	Carboniferien	Karbon	
	(1) Pennsylvanian or Upper Carboniferous (*a*) Monongahela or Upper Productive Measures (*b*) Conemaugh or Lower Barren Measures (*c*) Allegheny or Lower Productive Measures (*d*) Pottsville or Millstone Grit	(1) Upper Carboniferous (*a*) Coal Measures (*b*) Millstone Grit	(*a*) Stephanien or Ouralien (*b*) Westphalien or Muscovien (*c*) Namurien	Oberkarbon (*a*) Ottweiler (*b*) Saarbrucken	
	(2) Mississippian or Sub-Carboniferous (*a*) Mauch Chunk (*b*) Pocono	(2) Lower Carboniferous; Culm, or Limestone series	Dinantien	Unterkarbon Kulm or Kohlenkalk	Carboniferous
	Devonian	Devonian	Devonienne	Devon	Devonian
	Silurian	Silurian	Silurien	Ober-Silur	Silurian
	Ordovician	Lower Silurian	(1) Goth-Landien (2) Ordovicien	Unter-Silur	Ordovician
	Cambrian	Cambrian	Cambrién	Kambrium	Cambrian
Pre-Cambrian	Proterozoic or Algonkian Archaeozoic or Archean	Archean	Pre-Cambrién or Archéen	Eozoisch or Archaozoisch	Algonkian Archean

The following table shows the geological distribution of the different types of coal on the various continents and their relative abundance. More detailed tables are given for the individual continents where the coal resources of those continents are described.

TABLE SHOWING THE GEOLOGICAL DISTRIBUTION OF COAL BY VARIETIES

Period	North America	South America	Europe	Asia	Africa	Oceania
Quaternary..........	l		l	l	l	l
Tertiary.............	S**B**LAB	BL**B**	B L	**B**BL	L	L
Cretaceous...........	A**B**LBS	B **B**	B L	b	**B**	l
Jurassic and Triassic	a**b**lb	a	B l	ASBL	B	aB
Permian.............	b	b	A B	B	B c	B
Permo-Carboniferous		b		AB**B**	ABl	B**B**
Carboniferous.......	ABS**B**		ABcl	A S		b
Lower Carboniferous.	aBs		ABS	B		
Devonian...........			b			

A, Anthracite; S, Semibituminous; B, Bituminous; **B,** Subbituminous; L, Lignite, including brown coal; C, Cannel. Capital letters are used to indicate large and important deposits and lower case for small or unimportant deposits of the same variety

Geographically, coal is almost universally distributed as there are very few countries which do not have some coal. Even Antarctica has a considerable supply. There are a few countries, including Egypt, Thibet and Bolivia, which do not report any workable deposits. Norway has little or none outside of Spitzbergen and her other northern islands. Switzerland has had very small supplies and they are said to be nearly exhausted. Many other countries have very little coal in proportion to their political importance. Such are, for example, Italy, Roumania, Sweden, Brazil and the Argentine Republic. Japan is poorly supplied in proportion to her population and she will no doubt expect to control large areas on the mainland of Asia to take care of her industrial development, because history

has shown that the accessibility of large coal supplies is an essential factor in the great industrial development of any country. A glance at the table showing the coal resources of the various continents will show that Africa and South America are not well supplied with coal, although no doubt further geological work on these continents will reveal much larger resources than are here indicated. North America is lavishly supplied, and Europe, Australia and eastern Asia have plenty. The distribution of the coal deposits will have a very important bearing on the future economic history and commercial relations of these continents and especially on those of certain countries. This is well illustrated by the international problems arising from the distribution of coal during the war and immediately following it.

The following table will show the coal resources of the world by continents, in so far as geological data exist regarding them. This is the best and most complete estimate which has so far been compiled.

(1) COAL RESOURCES OF THE WORLD BY CONTINENTS
(In million metric tons; 1 metric ton = 1.1023 short tons)

	Class A	Classes B and C	Class D	Totals
	Anthracite and some dry coals	Bituminous coals	Subbituminous, brown coals and lignites	
Oceania	659	133,481	36,270	170,410
Asia	407,637	760,098	111,851	1,279,586
Africa	11,662	45,123	1,054	57,839
America	22,542	2,271,080	2,811,906	5,105,528
Europe	54,346	693,162	36,682	784,190
Totals	496,846	3,902,944	2,997,763	7,397,553

(1) From the Coal Resources of the World. Twelfth International Geological Congress, Morang & Company. For detailed discussion of classes of coal see Classification of Coals, Chapter V. The above estimates include all seams 1 foot and over in thickness and less than 4000 feet deep; and 2 feet and over in thickness and between 4000 and 6000 feet below the surface.

The outstanding features indicated in this table are the tremendous amount of coal in America and anthracite in Asia. The latter is mostly in China. It seems probable, however, that much coal has

been classed as anthracite in China which will turn out to be semi-bituminous or high-grade bituminous coal. Nevertheless, China far surpasses all other countries combined in her resources in this variety of coal. America has little anthracite in comparison with her resources in bituminous and brown coals.

The following table from Mineral Industry shows the coal production of the various countries of the world from the year 1911 to 1916. During the war the production of some countries almost ceased and since the beginning of the war it has been impossible to secure accurate data concerning the production of many countries. As indicated by the table, the output of the United States has increased rapidly and her production has almost passed the 600,000,000-ton mark. She has also become the leading exporter of coal since the exports of Great Britain have decreased from over 75,000,000 tons before the war to less than 20,000,000 in 1919, while those of the United States have more than doubled and are now said to be over 30,000,000 tons per annum. Few of the great industrial countries can look forward to exporting high-grade coal in very large quantities for an indefinite period because of the rate of increase in domestic requirements and the exhaustion of the more accessible seams.

(1) COAL PRODUCTION OF THE WORLD IN SHORT TONS FOR YEARS 1911–1916

Country or State	1911	1912	1913	1914	1915	1916
United States	496,371,126	534,466,580	569,960,219	513,525,477	531,619,487	597,474,000
Great Britain	304,518,927	291,666,299	321,922,130	297,698,617	283,570,560	287,110,153
Germany	258,223,763	281,979,467	305,714,664	270,594,152	259,139,786	
Austria-Hungary	54,960,298	56,954,279	59,647,957	(d) 53,396,400	(d) 52,679,712	50,801,602
France	43,242,778	45,534,448	45,108,544	33,360,885	19,908,892	(a) 22,000,000
Russia	29,361,764	33,775,754	37,188,480	36,414,560	31,158,400	28,962,724
Belgium	25,411,917	25,322,851	25,600,960	(a) 19,000,000	15,691,465	(a) 19,900,000
Japan	19,436,536	21,648,902	23,988,292	21,700,572	22,596,750	22,189,969
India	13,494,573	16,471,000	18,163,856	18,430,974	19,156,404	19,325,637
China	16,534,500	16,534,500	15,432,200			(a) 24,000,000
Canada	11,323,388	14,512,829	15,012,178	13,594,984	13,269,023	14,461,678
New South Wales	9,374,596	10,897,134	11,113,865	11,663,865	10,582,889	11,262,420
Transvaal	(b) 7,112,254	7,591,619	8,191,243	7,778,706	9,275,083	11,200,370
Spain	4,316,245	4,559,453	4,731,647	4,897,360	5,414,475	6,055,727
New Zealand	2,315,390	2,438,929	2,115,834	2,548,664	2,208,624	2,527,991
Holland	1,628,097	1,901,902	2,064,608	1,928,540	2,262,148	
Chile	1,277,191	1,470,917	1,362,334			
Queensland	998,556	1,010,426	1,162,497	1,180,825	1,147,186	1 016,654
Mexico	(a) 1,400,000	982,396				
Bosnia and Herzegovina	848,510	940,174	927,244			
Turkey	799,168	909,293				
Italy	614,132	731,720	772,802	861,265	1,042,748	1,439,538
Victoria	732,328	664,334	668,524	691,640	588,104	463,074
Orange Free State (e)	482,690	525,459	609,973	699,217	727,531	
Dutch East Indies	(a) 600,000	622,669	453,136	440,905		
Indo-China	(a) 460,000	471,259				
Sweden	343,707	397,149	401,199	404,143	454,432	457,262
Servia	335,495	335,000				
Western Australia	(a) 300,000	330,488	351,687	357,515	321,066	337,709
Peru	(a) 300,000	307,461	301,970	312,897	318,563	351,703
Formosa	280,999	306,941				
Bulgaria	270,410	324,511				
Rhodesia	212,529	216,140	237,728	391,394	458,934	491,532
Roumania	266,784					
Korea	138,508					
Tasmania	(a) 70,000	59, 987	61,648	68,130	66,000	62,244
British Borneo	(a) 100,000		49,762	128,505		
Spitzbergen	44,092					
Brazil	16,535					
Portugal	(a) 10,000	16,938	27,653	32,743		
Venezuela	(a) 10,000	(a) 12,000	13,355			
Switzerland	8,267					
Philippine Islands	(a) 2,000	2,998				
Unspecified	(a) 1,016,947					
Totals	1,309,574,000	(c) 1,377,000,000	(c) 1,478,000,000	(c) 1,334,000,000	(c) 1,270,000,000	

(1) From Mineral Industry, 1917.

(a) Estimated. (b) Transvaal, includes Natal and Cape of Good Hope and figures are only for coal sold. (c) Approximate. (d) Hungarian production estimated at 10,000,000 short tons. (e) Represents only coal sold, probably 10 to 12 per cent less than production.

CHAPTER XIII

THE COAL FIELDS OF THE WORLD — AMERICA

Introduction

America is here considered as two units — North and South. America undoubtedly has the greatest coal deposits of the world, but it is a striking fact that so far as our knowledge of the resources of the two continents extends the southern contains only about six-tenths of one per cent as much coal as the northern continent. A better knowledge of the geology of South America will no doubt extend her known resources but the disparity between the future supplies of the two continents will profoundly affect their trade relations.

North America

In a discussion of North America's coal deposits there are included those of Canada, Newfoundland, the West Indies, the United States, including Alaska, Cuba, Mexico and Central America. The following table shows the relative resources of these countries in so far as we have reasonably definite knowledge regarding them. Mexico has considerable good coal but her resources are not well known outside of a few areas explored by American or European companies.

This table shows the great extent of the coal supplies of the United States in those types of coal which are used so much in the industries. Canada is also unusually well supplied with bituminous coal and with lower grades but she is deficient in anthracite and in related high-carbon coals. This deficiency will probably not be so keenly felt in the future, however, as it has been in the past, because with the development of the use of partially devolatilized fuels such as carbocoal a substitute for anthracite will be provided in many parts of the country. The coal deposits of Canada and the United States, especially of the latter, have been gone over fairly well, and the above estimate of the resources may be regarded as comparatively accurate. Considerable

changes will be made, however, in these figures as more geological work is done, particularly in those for Canada since there are very large areas in Canada on which little field work has been completed.

ESTIMATE OF THE COAL RESOURCES OF NORTH AMERICA
(In million metric tons; 1 metric ton = 1.1023 short tons)

	Class A	Classes B and C	Class D	Totals
	Anthracite and some dry coals	Bituminous coals	Subbituminous coals, brown coals and lignites	
Newfoundland...	....	500	....	500
Canada.........	2,158	283,661	948,450	1,234,269
United States...	19,684	1,955,521	1,863,452	3,838,657
Central America	....	1	4	5
Total.........	21,842	2,239,683	2,811,906	5,073,431

Table from The Coal Resources of The World, Morang & Co., 1913. A detailed statement regarding the different classes of coal may be found in Chapter V on Classification of Coals. The estimates include all seams 1 foot and over in thickness and 4000 feet or less in depth; and all seams 2 feet and over in thickness and between 4000 and 6000 feet in depth.

The geological age of the coals in North America ranges from Mississippian, or Sub-Carboniferous, to Pleistocene, the main periods for their formation being the Upper Carboniferous, or Pennsylvanian, the Cretaceous, and the Tertiary. The table given below shows their geological distribution.

GEOLOGICAL AGE OF COALS OF NORTH AMERICA

					Canada										United States							
	Newfoundland	Mexico	Central America	Trinidad	Nova Scotia	New Brunswick	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia	Yukon Territory	N. W. Territory	Arctic Islands	Appalachian Region	Atlantic Coast Region	Interior Province	Gulf Coast Province	Great Plains Province	Rocky Mountain Province	Pacific Coast Province	Alaska
Pleistocene							l				l											l
Pliocene																						l
Miocene											l									l	l	a**AB**
Eocene		**b** l						l	L	B L	L	L						**B**L	**B**L	**B**L	a**a** B**B** L	b**BL**
Tertiary undifferentiated			l	**b** l							b l		L	l								
Upper Cretaceous		B							**b** L	**b** B l	B		l					**b**	B**B** L	A**A** **BB**		**B**B
Lower Cretaceous										a **A** B S	B S	B							B	B		
Jurassic																						**b**Bl
Triassic		a **a** s														**a**B						
Permian															b		b					
Pennsylvanian	B				B	b									**a**A BS		B					**b**
Mississippian					b									**B** C	a**a** s							**B**

A. Anthracite; **A.** Semianthracite; S. Semibituminous; B. Bituminous; **B.** Subbituminous; L. Lignite and brown coal. Capital letters indicate important deposits and lower case relatively unimportant to unworkable deposits of the same type.

PLATE XI. — The Coal-fields of Canada.

(After D. B. Dowling Canadian Geological Survey.)

THE COAL DEPOSITS OF CANADA[1]

The production, and the geological age, of the coals of Canada have been given in the preceding tables and the following table sums up the distribution and the characters of the coals in the various provinces as worked out by D. B. Dowling.

COAL RESOURCES OF CANADA

District	Actual Reserve Calculation based on actual thickness and extent			Probable Reserve (Approximate estimate)		
	Area Sq. Miles	Class of coal	Metric tons (1 metric ton = 1.1023 short tons)	Area Sq. Miles	Class of coal	Metric tons
Nova Scotia......	174.31	B_2	2,137,736,000	273.5	B_2	4,891,817,000
		C	50,415,000		C	20,000,000
New Brunswick..				121	B_2	151,000,000
Ontario...........				10	D_2	25,000,000
Manitoba........				48	D_2	160,000,000
Saskatchewan....	306	D_2	2,412,000,000	13,100	D_2	57,400,000,000
		D_2			D_2	26,450,000,000
		D_1	382,500,000,000		D_1	464,821,000,000
Alberta..........	25,300	B_3	1,197,000,000	56,375	B_3	139,161,000,000
		B_2B_1	2,026,800,000		B_2B_1	43,022,600,000
		A_2	669,000,000		A_2	100,000,000
		A_2B_2	23,653,242,000		A_2B_2	40,807,700,000
British Columbia	439	B_3	118,000,000	5,595	B_3	2,300,000,000
		D_2	60,000,000		D_1D_2	5,136,000,000
					C	1,800,000,000
Yukon...........				2,840	A_2B_3	250,000,000
North-West Territories.....				300	D_1D_2	4,690,000,000
					D_2	4,800,000,000
Arctic Islands....				6,000	B_2B_3	6,000,000,000
					C	
Totals..........	26,219.31		*414,804,193,000	82,662.5		801,966,117,000

* 20,000,000 tons deducted for the amount of coal already exhausted in Alberta. Table from Coal Resources of the World. For details of classes of coal see Classification of Coals, Chapter V. This table contains all seams of 1 foot or over to a depth of 4000 feet.

[1] For detailed accounts of the coal deposits of Canada see The Coal Resources of the World, Twelfth International Geological Congress, (Morang & Co.), An Economic Investigation of the Coals of Canada, by J. B. Porter and R. J. Durley, Department of Mines, Canada; The Coals of Canada, by D. B. Dowling, Memoir 59, Canadian Geol. Survey, 1915; and The Coal Fields of British Columbia, by D. B. Dowling, Memoir 69, Canadian Geol. Survey, 1915.

In addition to the figures mentioned here there might be added 17,499,000,000 metric tons of coal of Class B_2 which occurs in seams over 2 feet thick lying at a depth between 4000 and 6000 feet, in the provinces of Nova Scotia, Alberta and British Columbia.

From the accompanying map (Plate XI) it will be observed that the coal deposits of the Dominion are almost all located in the extreme eastern and in the western parts of the country. Quebec and Ontario, the most populous and the most important of the provinces commercially have no good coal and they receive most of their supply from the United States. Quebec is without coal of any kind and Ontario has a few million tons of low-grade lignite in the interglacial deposits south of James Bay. Nova Scotia on the east and Alberta and British Columbia on the west have high-grade coal in large quantities while Saskatchewan and Alberta have very large resources in lignite and subbituminous coal.

Nova Scotia. — The coal of Nova Scotia is all of Pennsylvanian, or Upper Carboniferous, age except for thin and unmined seams in the Mississippian, or Lower Carboniferous. Thin seams occur in the Millstone grit but most of the coal lies above this formation. There are five important areas producing coal — the Joggins and Springhill areas in the Cumberland field; the Pictou, Inverness and Cape Breton, or Sydney, fields. In the Joggins area there are two seams 3 to 5 feet in thickness, and the beds are inclined at angles of as much as 50°. The coal is of fairly good quality but is high in ash. This area has been famous for its buried Carboniferous trees which are abundant in the sandstones of the Coal Measures. The Springhill area is considerably faulted and it seems to represent the central part of the basin in which the Joggins seams were laid down. There are a number of seams of which five can be mined and they make up a total of about 50 feet of coal, the thickest seam reaching 13 feet. In the Pictou field there is a little coal in the Millstone grit and in the Permian, but all the workable coal occurs in the Coal Measures proper, in two large fault blocks. One fault has a downthrow of about 2600 feet. There are four seams in the Westville area of this field varying from 6 to 18 feet in thickness and separated from one another by from 90 to 260 feet of strata including some beds of oil shales. As a rule the beds dip gently. In the Stellarton area of the Pictou field there are 9 seams, some of which are very

thick. The Main seam varies from about 6 feet to 45 feet in thickness and the Deep seam from 20 to 33 feet. The other seams are rather thin. There is one bed of oil shale with a coal seam, in this area. It is 5 feet in thickness and it was formerly mined for the extraction of oil.

FIG. 109. — Allen Shaft, near Stellarton, Pictou coal field, Nova Scotia. (Photo by H. Ries.)

The Inverness field is largely under the sea. The measures dip seaward at from 12° to over 75° and the seams mined run about 6 to 7 feet in thickness.

In the Sydney field, which occupies the northern part of Cape Breton County the Coal Measures dip gently seaward, being disturbed by only small folds. They have been mined on the slope under the sea for more than a mile from the shore. The number of seams in this field varies from 1 to 12 with an aggregate thickness of coal

from 1 foot to 46 feet. It is expected that the workings will in time extend nearly 3 miles from the shore.

New Brunswick. — In New Brunswick the upper members of the Pennsylvanian are lacking. The Millstone grit is widely distributed over the province and it contains a few thin seams of which one is worked where it runs around 18 inches and over in thickness. The seams are shallow, the coal is high in ash and sulphur but lends itself readily to hand picking. A little anthracite is reported from Lepreau in St. Johns County.

FIG. 110. — Coal seam (retouched) in sea cliff on coast of Nova Scotia. (Photo by H. Ries.)

Ontario. — There is a small area of about 10 square miles along the lower part of the Moose River, south of James Bay, which is underlain by lignite. This coal was formed in an interglacial period and it lies between two beds of boulder clay. It is suitable for future briquetting operations. There are no Carboniferous rocks in Ontario and Quebec. The formations are largely pre-Cambrian, except for some older Palaeozoics in the southern part of Ontario and around James Bay.

Manitoba. — In the Tertiary rocks capping a hill called Turtle Mountain and in adjacent hills along the International Boundary there are some seams of lignite. The eastern part of Manitoba is covered with pre-Cambrian rocks and the western portion chiefly by marine Cretaceous.

Saskatchewan. — The coal of Saskatchewan occurs in the Tertiary and Upper Cretaceous formations. The Tertiary formations seem to correspond to the Fort Union lacustrine and land-formation stage of the Eocene in North Dakota, and they are found in the hilly country in the southern part of the province. The strata lie practically flat except for a syncline under the Souris River Valley and the seams outcrop along ravines and on hillsides. A good deal of coal is mined in the Souris Valley region and in a number of other places, and wagon mines are common as many of the western farmers dig their own coal. The Tertiary coal is practically all lignite and the maximum thickness of the seams is about 20 feet. The Cretaceous coals occur in the Belly River formation of the Upper Cretaceous along the Saskatchewan River, in the western part of the province. The coal lies from 200 to 300 feet below the surface and there are at least two seams about 4 feet and 8 feet thick respectively. They are not uniform in thickness or regular in distribution. This coal also is lignite. A little lignite occurs in the Middle Cretaceous south of Lac la Rouge.

Alberta. — In the province of Alberta coal occurs in the Kootenay series of the Lower Cretaceous; in the Belly River series, corresponding to the St. Pierre of the Montana series of the Upper Cretaceous; and in the fresh-water deposits of the Edmonton formation, corresponding to the Fort Union beds of the Eocene.

The Kootenay series, regarded as lacustrine and terrestial in origin, contains the best coals of Canada, they being bituminous to anthracite. It lies deeply buried beneath the younger sediments except where it is brought to light in the folds along the foothills or in the great fault blocks of the Rocky Mountains. Its thickness varies from 200 to about 3000 feet. The coal-bearing area in Alberta extends from the International Boundary northward beyond the Athabasca River and while little development work or even prospecting has been done in much of this great area, several very important mining districts have developed. The most important of these is in

the region of Crowsnest Pass on the Crowsnest branch of the Canadian Pacific Railway. Mines occur at several places in the Blairmore-Frank region. A half dozen seams occur, ranging from 3 to 17 feet in thickness. It was at Frank that the famous landslide occurred which carried away a section of Turtle Mountain. It destroyed a number of houses in the town, killing ninety-three people, and it buried the railroad through the valley, (Fig. 111). The track was so deeply

FIG. 111. — Débris from the landslide at Frank, Alberta, partly covering the town. (Photo by E. S. Moore.)

buried that a new line was constructed over the débris which consisted chiefly of great blocks of limestone. The lower portions of the mountain are composed largely of shales and coal seams, while the upper portion contains heavy beds of limestone. The mining operations, which had been carried well through the mountain, apparently disturbed the overlying strata and a large crack developed which caused a tremendous mass of rock to break away, slide down the mountain and across the valley.

In the Coleman area there are three seams as much as 8, 10 and 16

feet in thickness, respectively, within a thickness of 300 feet of strata. In the Livingstone basin lying a short distance northward from the Blairmore-Frank region, there are in Cat Mountain as many as twenty-one seams with a total of about 125 feet of coal. On the west fork of the McLeod River southeast of Folding Mountains there are four seams

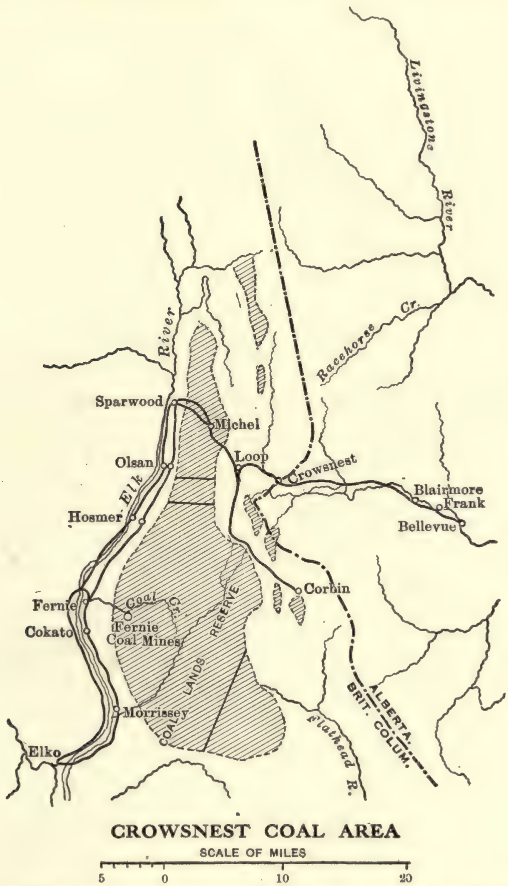


FIG. 112. — Map of the Crowsnest coal area. (After D. B. Dowling.)

in the Folding Mountain anticline on the eastern limb and they vary from 2 feet to 28 feet in thickness. On the western limb a combination of seams forms one mass as much as 50 feet thick.

In the Cascade area there is a continuous coal field extending for about 90 miles from south of the Kananaskis River northward to near

the Saskatchewan River. This is a great fault block with a fault running along the western edge of the coal field. In some portions there are between 15 and 20 seams of coal with a maximum aggregate thickness of nearly 100 feet. Remnants of a very extensive coal-bearing area are found along the Bow River and there are mines at Canmore. At Bankhead, not far from Banff, semi-anthracite and anthracite are mined, and mines were formerly worked at Anthracite. These beds have been highly squeezed. Other important areas in Alberta are the Bighorn, Brule Lake, Nikanassin, Muskeg River, Shunda Creek, Costigan, and Moose Mountain in the foothills near Calgary. In Folding Mountain the beds are highly folded so that they are practically vertical.

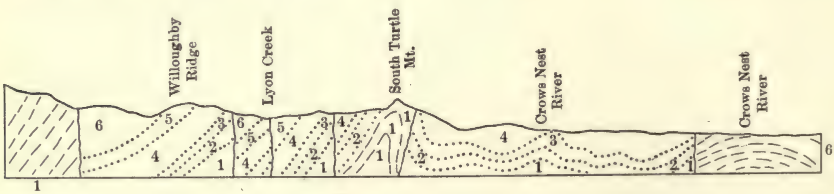


FIG. 113. — Structure section through the Blairmore-Frank region, Alberta. 1, Devono-carboniferous; 2, Lower cretaceous or jurassic (Fernie shales); 3, Coal measures; 4, Equivalent of flathead beds; 5, Volcanic ash and agglomerates; 6, Upper cretaceous and laramie; 3–6, Cretaceous. Scale 4 miles = 1 inch. (After D. B. Dowling, Canadian Geol. Survey.)

The abundance and high quality of the coal in western Alberta and the adjoining portion of British Columbia make this region the most promising coal-mining region of Canada. There is a great deal of good coking coal.

The Belly River formation underlies about 16,000 square miles in eastern Alberta. The best coal in this formation is being mined at Lethbridge. The coal improves as the mountains are approached. Around Medicine Hat two seams, each about 5 feet thick, are exposed along the Bow River. In the vicinity of Calgary the Belly River formation is struck at depths of from 2560 to 2875 feet and the coal varies from 4 to 7 feet in thickness. At Edmonton the depth is about 1400 feet and the coal about 6 feet thick. In the Peace River Valley there is some coal in the Dunvegan series supposed to be equivalent to this formation. There is much coking coal in the Belly River formation.

The Edmonton (Eocene) series occurs in a large synclinal basin which runs nearly parallel to the Rocky Mountains and extends over about 4 degrees of latitude. The dips are steep on the western and low on the eastern limb of the basin and the basin flattens out to the northwestward. At Calgary there is a seam of lignite about 13 feet thick

FIG. 114. — Peaks behind Canmore, Alberta. About two-thirds of mountain face is Palaeozoic strata thrust over folded Mesozoic coal measures. (Photo by H. Ries.)

under cover of 1800 feet of poorly consolidated sandstone and clay. On the North Saskatchewan, west of Edmonton, a 25-foot seam outcrops and on the Grand Trunk Pacific Railway line at the Pembina River crossing it splits into two seams each 10 feet thick. About 500 feet below this seam several smaller seams occur over several

thousand square miles and they are mined at Edmonton, Tofield and at other places between Edmonton and Calgary. The coal varies from lignite in the northwestern part of the basin to a subbituminous and coking coal in the foothills of the Rockies.

British Columbia.[1] — The coal deposits of this province are grouped by Dowling under the five following heads: Southern, Central and Northern British Columbia, Vancouver Island and Queen Charlotte Islands. In the Southern district is located the Crowsnest area which is a basin of about 230 square miles around which lower beds have been uplifted and then eroded on a large scale leaving the coal field as an elevated plateau. The coal occurs here, as elsewhere in the Rocky Mountains, in the Kootenay series of the Lower Cretaceous and most of the better seams occur in the lower 2000 feet. It is said, however, that these upper seams are very largely cannel or other high volatile coals.

The following is a tabulation of the seams in this area:

At Morrissey	23 seams with 216 feet of coal	in 3676 feet of measures
At Fernie	23 seams with 172 feet of coal	in 2250 feet of measures
At Sparwood	23 seams with 173 feet of coal	in 2050 feet of lower measures
At Sparwood	24 seams with 43 feet of coal	in 2015 feet of upper measures

At Corbin a seam 80 feet thick is worked. The coal is in places highly faulted and folded and it is worked from tunnels. The coal-bearing strata occupy a basin which is in a hill, and on top of the hill there is so little cover that the coal, which is here 125 feet thick, is stripped and mined by steam shovels.

The Flathead River area lying about 12 miles north of the International boundary gives promise of being a very important field for its size. It is probably a faulted block with the strata dipping only about 20° and exposing four seams which are 16, 20, 30 and 50 feet thick, respectively. The Upper Elk River area north of the Crowsnest area will probably be an important field as there are as many as eighteen seams in one section and there is an aggregate of 182 feet of coal in 1200 feet of strata. One seam reaches 31 feet in thickness. The coal in this area as in the others mentioned above is high-grade bituminous coal and it is used largely for coking.

At Princeton on the Similkameen River there is a small basin con-

[1] Coal Fields of British Columbia, Compiled by D. B. Dowling, Memoir 69. Geol Survey, Canadian Department of Mines, 1915.

taining lignite of Oligocene age. There are as many as seventeen seams in one section and the thickness varies from 1 foot to 18 feet. South of Tulameen similar lignite of Oligocene age occurs with two or three seams from 12 to 20 feet thick. In the Nicola and Quilchena basins there are also Oligocene deposits. Several collieries have been opened near the mouth of Coldwater Creek in the Nicola basin and in that region four seams running from 5 to 12 feet in thickness are mined. The coal is used for locomotives as it is of better grade than the lignite in the other regions. The basin is considerably broken by faults and it has been overlain by basalt flows.

In the Central British Columbia region a number of coal deposits occur but many of them have not been proven to be of special importance. In the valley of the Bear River bituminous coking coal was found along the Grand Trunk Pacific Railway in three seams running from 4 feet to 9 feet in thickness. It is of Tertiary age. On the southern tributaries of the Skeena River the Lower Cretaceous rocks carry a few seams of mineable bituminous coal. In the Telka River area some thick seams of coal, 19, 24 and 13 feet in thickness occur. The coals are reported to be of coking quality.

Several areas of coal-bearing rocks occur in the Northern British Columbia district. In the Groundhog Mountain area on the head waters of the Skeena, semianthracite coal occurs in Lower Cretaceous rocks of the Skeena series, resting on Jurassic volcanics. The area is greatly broken by faults. In the Peace River district there is a projection of the coal formations described for Alberta. Tertiary lignites also occur on the Liard and Taku rivers but the deposits are little known.

The coal seams of Vancouver Island are of Upper Cretaceous age, according to C. H. Clapp, and they occur in the Nanaimo series which is supposed to be largely estuarine in origin and is about 10,000 feet thick. The topographic conditions during its formation were not uniform and the beds in many cases lack persistency. The series has in places been greatly folded and faulted. The coal is of bituminous quality. There are six main basins as follows: Quatsino Sound at the northern end of the island; Suquash on the east coast; Comox, Nanaimo and Cowichan, all on the Strait of Georgia; and the Alberni in the central part of the island. The Suquash, Comox and Nanaimo basins contain seams which are being worked. In the Suquash

basin the beds are little disturbed and regular. The coal is a low carbon, high moisture, bituminous coal. In the Comox basin the lower seams lie over an irregular bottom and are quite irregular in thickness and distribution. In some places the coal is broken and coked by igneous intrusions. It is bituminous and coking and has the highest fuel ratio of any of the Vancouver Island coals. In the Nanaimo field there are many faults and the seams vary very greatly in thickness and quality within short distances, but they are quite persistent in extent. A case is cited by Clapp where a seam varies, within 100 feet, from 2 feet of dirty slickensided coal to 30 feet of clean coal. There are three seams with an aggregate of 10 feet of coal which is a high-volatile, coking, bituminous variety. This basin has produced the larger part of the coal of British Columbia.

The coals of the Queen Charlotte Islands are of two geological ages — Cretaceous and Tertiary, supposedly Miocene. The Cretaceous coals vary from high-volatile bituminous to semianthracite and the Tertiary are subbituminous coals and lignites, some of the latter of very woody types. Part of the Cretaceous coal is coking. The semianthracite is unusually high in water and much of it is high in ash. The main basin lies on the southern end of Graham Island where the shales have been highly folded between masses of crystalline rocks. In some places the coal is greatly crushed. The Tertiary coals are not of much importance.

Yukon Territory. — Coal has been mined at five points in the Yukon: Tantalus Mine, and Five Fingers Mine on the Yukon River; on Cliff Creek; on Coal Creek, a tributary of the Yukon; and on Coal Creek, a tributary of Rock Creek. According to the conclusions of D. D. Cairnes, the coals are Jura-Cretaceous and Tertiary in age. The Tertiary coals are upper Eocene and they are lignites with considerable resin. In places volcanic rocks are associated with the soft shales and clays and loosely cemented conglomerates and sandstones.

There are two coal horizons in the Jura-Cretaceous rocks, the upper being the Tantalus conglomerates, about 1000 feet thick, and the lower the Laberge series about 3800 feet in thickness. The coal seams occur near the top of the latter series which consists of arkoses, graywackes, sandstones, tuffs, shales and slates. The coal is bituminous and in most places non-coking. The coal of the lower seam

when washed produces commercial coke. Some semianthracite occurs in the Whitehorse area.

Northwest Territories. — There are several coal basins in this region. One of these in Tertiary rocks, occurs in the Mackenzie River valley and runs a short distance up the Bear River at Fort Norman. There is probably a lignite area running south up the valley of the Mackenzie from Fort Norman and an area around the northwest side of Great Bear Lake. Three seams have been reported with a maximum of about 16 feet of coal.

FIG. 115. — The Tantalus coal mine on the Yukon River. (Photo by E. S. Moore.)

Along the Peel and Horton rivers in the vicinity of the Mackenzie delta there are Cretaceous rocks carrying thin seams of coal with a maximum thickness of 4 feet. Some of the seams have been on fire in the past, producing reddened outcrops which offer striking features to the traveler. So far as known all the coal in the Territories is lignite.

The Arctic Islands. — Very little accurate information regarding the coal deposits on the Arctic Islands has been obtained but it is known that coal occurs at two horizons, in the Tertiary and in the Lower Carboniferous. The Tertiary coals are lignites and the older

coals are bituminous. It is estimated that some 6000 square miles on Banks Island and the Parry Islands is underlain with Lower Carboniferous coals. Only one seam has been found but it is said to reach a maximum of 50 feet in thickness. Small deposits of Tertiary coal are believed to exist on Ellsmere, Baffin and Bylot islands. On Ellsmere Island a seam of Tertiary coal 25 feet thick has been reported from Cape Murchison. Cannel coal and oil shale have been found on the Parry Islands.

Newfoundland

Owing to the prominence of the large and well developed coal deposits in Nova Scotia little attention has been paid to the Newfoundland deposits which are not so extensive nor so readily mined as those in Canada. There are, however, at least two areas of Carboniferous rocks which carry considerable coal in Newfoundland. One area is on St. George Bay and the other is about 100 miles northeast of it in the Humber River valley. In the former area there are, according to J. P. Howley, as many as nine seams varying in thickness from 1 foot to 9 feet. The beds are greatly disturbed and many of the seams are of small extent.

In the Humber River valley the strata are for the most part older than the Pennsylvanian and they carry oil shales and material resembling the albertite of New Brunswick. There are, however, in parts of the district small areas of the Coal Measures which carry several workable seams running up to about 6 feet in thickness and some of the seams are greatly folded although in much of this field the strata are nearly flat. The Newfoundland coals are bituminous to semibituminous in character.

Coal Deposits of the United States

PRODUCTION

The United States not only has the largest deposits of coal of any country in the world but she is also developing them at a more rapid rate than any other country. A preceding table (page 335) shows the relative production of the countries of the world and the following table indicates the rank of the various states of the Union in production and the value of the coal produced. Pennsylvania has long been the chief producer in the country.

[1]COAL PRODUCTION OF THE UNITED STATES FOR THE YEARS 1913 TO 1917 INCLUSIVE

State	1913 Quantity (net tons)	1913 Value	1914 Quantity (net tons)	1914 Value	1915 Quantity (net tons)	1915 Value	1916 Quantity (net tons)	1916 Value	1917 Quantity (net tons)	1917 Value
Alabama	17,678,522	$23,083,724	15,593,422	$20,849,919	14,927,937	$19,066,043	18,086,197	$24,859,831	20,068,074	$45,616,992
Arkansas	2,234,107	3,923,701	1,836,540	31,158,168	1,652,106	2,950,456	1,994,915	3,836,845	2,143,579	5,492,777
California and Alaska	26,911	95,173	(a) 13,974	(a) 39,821	(a) 13,903	(a) 35,354	(a) 20,313	(a) 67,684	(a) 60,378	(a) 280,108
Colorado	9,232,510	14,035,090	8,170,559	13,601,718	8,624,980	13,599,264	10,484,237	16,964,104	12,483,336	27,669,129
Georgia	255,626	361,319	166,498	239,462	134,496	231,861	173,554	310,093	119,028	301,391
Idaho and Nevada	2,177	5,285	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Illinois	61,618,744	70,313,605	57,589,197	64,693,529	58,829,576	64,622,471	66,195,336	82,457,954	86,199,387	162,281,822
Indiana	17,165,671	19,001,881	16,641,132	18,290,928	17,006,152	18,637,476	20,093,528	25,506,246	26,539,329	52,940,106
Iowa	7,525,936	13,496,710	7,451,022	13,364,070	7,614,143	13,577,608	7,260,800	13,530,383	8,965,830	21,096,408
Kansas	7,202,210	12,036,292	6,860,988	11,239,253	6,824,474	11,360,630	6,881,455	12,252,723	7,184,975	16,618,277
Kentucky	19,616,600	20,516,749	20,382,763	20,852,463	21,361,674	21,494,008	25,393,997	30,193,047	27,807,971	60,297,653
Maryland	4,779,839	5,927,046	4,133,547	5,234,796	4,180,477	5,330,845	4,460,046	6,947,623	4,745,924	11,667,852
Michigan	1,231,786	2,455,227	1,283,030	2,559,786	1,156,138	2,372,797	1,180,360	2,653,182	1,374,805	4,426,314
Missouri	4,318,125	7,468,308	3,935,980	6,802,325	3,811,593	6,595,918	4,742,146	9,044,505	5,670,549	13,755,864
Montana	3,240,973	5,653,539	2,805,173	4,913,191	2,789,755	4,526,509	3,632,527	6,286,197	4,226,689	8,919,136
New Mexico	3,708,806	5,401,260	3,877,689	6,230,871	3,817,940	5,481,361	3,793,011	5,580,369	4,000,527	7,455,166
North Dakota	495,320	750,652	506,685	771,379	528,078	766,072	634,912	946,082	790,548	1,425,750
Ohio	36,200,527	39,948,058	18,843,115	21,250,642	22,434,691	24,207,075	34,728,219	46,150,907	40,748,734	100,897,148
Oklahoma	4,165,770	8,542,748	3,988,613	8,204,015	3,693,580	7,435,906	3,608,011	7,525,427	4,386,844	12,335,413
Oregon	46,063	116,724	51,558	143,556	39,231	111,240	42,592	113,976	28,327	95,663

[1]COAL PRODUCTION OF THE UNITED STATES FOR THE YEARS 1913 TO 1917 INCLUSIVE (*Continued*)

State	1913		1914		1915		1916		1917	
	Quantity (net tons)	Value	Quantity (net tons)	Value	Quantity (net tons)	Value	Quantity (net tons)	Value	Quantity (net tons)	Value
Pennsylvania bituminous	173,781,217	$193,039,806	147,983,294	$159,006,296	157,955,137	$167,419,705	170,295,424	$221,685,175	172,448,142	$ 421,268,808
South Dakota	10,540	20,648	11,850	20,456	10,593	16,384	8,886	18,021	8,042	23,346
Tennessee	6,860,184	7,839,721	2,943,258	6,776,573	5,730,361	6,479,916	6,137,449	7,522,445	6,194,221	13,592,998
Texas	2,429,144	4,288,920	2,323,773	3,922,459	2,088,908	3,445,487	1,987,503	3,092,663	2,355,815	4,177,608
Utah	3,254,828	5,384,127	3,103,036	4,935,454	3,108,715	4,916,916	3,567,428	5,795,944	4,125,230	8,531,382
Virginia	8,828,068	8,952,653	7,959,535	8,032,448	8,122,596	7,962,934	9,707,474	10,261,424	10,087,091	20,125,713
Washington	3,877,891	9,243,137	3,064,820	6,751,511	2,429,095	5,276,299	3,038,588	6,907,428	4,009,902	10,727,362
West Virginia	71,254,136	71,822,804	71,707,626	71,391,408	77,184,069	74,561,349	86,460,127	102,366,092	86,441,667	200,659,368
Wyoming	7,393,066	11,510,045	6,475,293	10,033,747	6,554,028	9,555,804	7,910,647	12,239,707	8,575,619	16,593,283
Total bituminous	478,435,297	565,234,952	422,703,970	493,309,244	442,624,426	502,037,688	502,519,682	665,116,077	551,790,563	1,249,272,837
Pennsylvania anthracite	91,524,922	195,181,127	90,821,507	188,181,399	88,995,061	184,653,498	87,578,493	202,009,561	99,611,811	283,650,723
Grand total	569,960,219	760,416,079	513,525,477	681,490,643	531,619,487	686,691,186	590,098,175	867,125,638	651,402,374	1,532,923,560

(*a*) California, Idaho and Nevada in 1914; California, Alaska, Idaho and Nevada in 1915; and California, Alaska, and Idaho in 1916 and 1917.
(*b*) Included with California.
[1] Mineral Resources of the United States, U. S. Geol. Survey, 1917, p. 922.

UNIV. OF CALIFORNIA

PLATE XII.—Map of the coal-fields of the United States (U. S. Geol. Survey.

nted by permission from Ries' Economic Geology, published by John Wiley & Sons, Inc.)

DISTRIBUTION BY KINDS OF COAL

The Geological Survey has adopted, according to M. R. Campbell, the following divisions in classifying the coal areas of the country, (Plate XII): (1) Coal province (2) Coal region (3) Coal field (4) Coal district. The following provinces have been recognized: (1) Eastern province; (2) Interior province; (3) Gulf province; (4) Northern Great Plains province; (5) Rocky Mountain province; and (6) Pacific Coast province. These provinces are subdivided into regions as follows: The Eastern province is divided into (*a*) The Anthracite region of Pennsylvania; (*b*) The Atlantic Coast region, including the Triassic fields of Virginia and North Carolina; (*c*) The Appalachian region extending from northern Pennsylvania into Alabama and embracing also parts of Ohio, Maryland, Virginia, West Virginia, Eastern Kentucky, Tennessee and Georgia. The Interior province is divided into (*a*) the Northern region, containing only the coal field of Michigan; (*b*) The Eastern region including the fields of Illinois, Indiana and Western Kentucky; (*c*) The Western region including the coal fields of Iowa, Missouri, Nebraska, Kansas, Arkansas and Oklahoma and (*d*) The Southwestern region, in Texas.

The Gulf province includes (*a*) The Mississippian region, in the east and (*b*) The Texas region to the west. The former includes the states of Louisiana, Mississippi and Alabama and the latter Arkansas and Texas.

The Northern Great Plains province includes (*a*) The Fort Union region with the lignite fields of North Dakota, South Dakota, eastern Montana and the subbituminous field of northeastern Wyoming; (*b*) The Black Hills region of Wyoming; (*c*) The Assinniboine region in Montana; (*d*) The Judith Basin region in Montana; (*e*) The Denver region in Colorado; and (*f*) the Raton Mountain region of Colorado and New Mexico.

The Rocky Mountain province is not clearly separated from the Great Plains province. It includes (*a*) The Yellowstone region of Montana; (*b*) The Bighorn Basin region of Wyoming; (*c*) The Hams Fork region of western Wyoming; (*d*) The Green River region of southern Wyoming; (*e*) The Uinta region of Utah and Colorado; (*f*) The San Juan River region of Colorado and New Mexico; and (*g*) The southwestern Utah region.

The Pacific Coast province is not divided into regions. It em-

braces coal fields in Calfornia, Oregon and Washington. It is the smallest of the provinces.

The following table, prepared by Campbell for the Twelfth International Geological Congress, presents the areas of the various provinces, the types of coal in each, and the character of the coal. The total production of each state to the end of 1917 has been added to show the extent of exhaustion of the resources. The estimate includes all seams not less than 14 inches thick and not more than 3000 feet below the surface. A detailed description of the classes of coal mentioned in this table is found in Chapter V under Classification of Coals.

The total estimated tonnage of all kinds of coal for the United States above 3000 feet in depth is 3,225,394,300,000 metric tons or about one-tenth more in short tons. The amount produced up to the end of 1917 was 12,130,805,450 short tons. By adding approximately 50 per cent of this amount for waste in mining and other operations the total coal exhausted is approximately 18,196,203,175 short tons. This is almost negligible compared with the coal resources of the country, being slightly more than one-half of one per cent, but in many fields the output represents the best coal from the most accessible seams.

TABLE OF ESTIMATED COAL RESOURCES OF THE UNITED STATES

Province State and Field	Area in Square Miles			Estimated original amount of coal in metric tons (metric ton = 1.1023 short tons of 2000 lbs.)						
	Known coal field	Possible coal field	Coal below 3000 feet	Lignite (No. 2 Class D)	Subbituminous coal (No. 1 Class D)	Bituminous coal (Class C and No. 2 Class B)	Semibituminous coal (No 1 Class B)	Anthracite and Semi-anthracite coal (Class A)	Coal below surface from 3000 to 6000 feet	*Total production of coal to end of 1917 in short tons
Eastern province:										
Pennsylvania:										
Anthracite region	480							19,056,300,000	Undetermined	2,813,702,882
Bituminous fields	14,200					93,080,000,000	9,074,000,000			3,380,627,056
Ohio	12,660					85,270,000,000				799,433,305
Maryland	455					1,368,000,000	5,932,000,000			193,173,673
West Virginia	17,000					111,293,500,000	27,132,000,000			1,109,282,513
Kentucky	10,270					61,513,000,000				303,075,049
Virginia:										132,164,477
Southwestern fields	1,550					18,829,400,000	227,000,000			
Brushy Mountain fields	200							817,000,000 (Semianthracite)		
Atlantic Coast region	150					544,000,000				
North Carolina	60					181,500,000				477,125
Tennessee	4,400					23,289,500,000				147,755,654
Georgia	167					846,600,000				10,018,874
Alabama:										323,629,988
Warrior and Plateau fields	7,845					57,634,600,000				
Cahaba field	268	82				3,421,000,000				
Coosa field	260					272,000,000				
	69,965	82				457,543,100,000	42,365,000,000	19,873,300,000		
Interior province:										
Michigan	11,000					10,889,300,000				27,906,044
Indiana	6,500					48,140,700,000				331,912,239
Kentucky	4,900	1,500				50,400,000,000				See above
Illinois	35,600					182,758,400,000				1,234,329,819
Iowa	12,560					20,461,000,000				217,894,892
Missouri	23,960					76,225,000,000				138,328,740
Kansas	18,600					27,223,200,000				157,448,653
Oklahoma	10,000					49,865,200,000				75,151,212
Arkansas	1,580					154,900,000	1,112,800,000	363,000,000 (Semianthracite)		44,186,728
Texas	8,200	5,300				7,259,500,000				35,405,289
	132,900	6,800				479,377,200,000	1,112,800,000	363,000,000		

TABLE OF ESTIMATED COAL RESOURCES OF THE UNITED STATES (*Continued*)

Province State and Field	Area in Sq. Miles: Known coal field	Area in Sq. Miles: Possible coal field	Area in Sq. Miles: Coal below a depth of 3000 feet	Estimate of original amount of coal, in metric tons: Lignite (No. 2 Class D)	Subbituminous coal (No. 1 Class D)	Bituminous coal (Class C and No. 2 Class B)	Semibituminous coal (No. 1 Class B)	Anthracite and Semi-anthracite coal (Class A)	Coal below surface from 3000 to 6000 feet	*Total production of coal to end of 1917 in short tons
Gulf province:										
Arkansas	100	5,900		81,700,000						See Interior province
Texas	2,000	53,000		20,871,000,000						
	2,100	58,900		20,952,700,000						
Northern Great Plains province:										
North Dakota	29,630	6,350		633,329,800,000						
South Dakota	2,160	8,820		925,900,000						7,883,739
Montana:										See below
Fort Union region	33,132			331,646,700,000						
Bull Mountain field	633	457			4,353,100,000					
Assinniboine region	3,000				2,722,300,000					
Judith Basin region	1,500					1,814,900,000				
Wyoming:										See below
Black Hills region	320					120,700,000				
Powder River region	10,800	3,200			124,750,500,000					
Colorado:										215,124,810
Denver region	5,380	1,480			36,297,700,000					
Canon City field	40					932,800,000				
Trinidad field	1,035		80			22,198,000,000				
New Mexico:										57,006,773
Raton field	960					16,270,400,000				
	88,590	20,357	80	965,902,400,000	168,123,600,000	41,336,800,000				
Rocky Mountain province:										
Montana:										54,854,203
N. F. Flathead River field	150				3,081,700,000					
Mountain fields	10	100			90,700,000					
Yellowstone region	50					42,900,000				
Red Lodge — Bridger field	50	450			1,535,200,000	552,500,000				

TABLE OF ESTIMATED COAL RESOURCES OF THE UNITED STATES (*Continued*)

Province State and Field	Area in Square Miles			Estimated original amount of coal in metric tons						
	Known coal field	Possible coal field	Coal below a depth of 3000 feet	Lignite (No. 2 Class D)	Subbituminous coal (No. 1 Class D)	Bituminous coal (Class C and No. 2 Class B)	Semibituminous coal (No 1 Class B)	Anthracite and Semianthracite coal (Class A)	Coal below surface from 3000 to 6000 feet	*Total production of coal to end of 1917
Rocky Mt. province (Cont.):										
Idaho:										
Goose Creek field	30				90,700,000					
St. Anthony field	200	1,000				544,500,000				
Wyoming:										148,256,505
Bighorn Basin region	905	430	2,830		907,400,000				1,800,000,000	
Wind River Basin region	160		3,340		1,828,600,000				9,100,000,000	
Hanna field	1,435	240			20,871,000,000	9,074,400,000				
Green River Basin region	6,440	870	9,970		370,472,000,000	57,196,200,000			180,000,000,000	
Hams Fork region	600				16,706,000,000	6,715,100,000				
Colorado:										See above
North Park field	57	43			2,588,600,000					
Yampa field	3,130				37,954,000,000	85,025,300,000		20,500,000	180,000,000,000	
Uinta Basin region	2,780		3,720			75,847,500,000		435,900,000	130,000,000,000	
South Park field	3	70				18,100,000				
Durango field	1,840	20			17,693,300,000	8,504,500,000				
Tongue Mesa field	40					842,300,000				
S. W. Colorado field	36					74,000,000				
Utah:										48,157,243
Uinta region	3,276		7,530			76,392,000,000			91,000,000,000	
Coalville field	20				141,700,000					
Colob Plateau field	350					3,629,800,000				
New Mexico:						Some impure anthracite				See above
San Juan River region	10,700		1,000		150,778,000,000				13,000,000,000	
Small fields	1,560				6,125,000,000	903,309,000		7,200,000		
Arizona:										
Black Mesa field	3,580				12,776,800,000					
Small fields	30				55,700,000	9,100,000				
	37,432	3,223	28,390		643,696,400,000	325,371,500,000		463,600,000		
Pacific Coast province:										
Washington	1,800				47,588,800,000	10,355,700,000		21,100,000		77,001,845
Oregon	90	140			907,400,000					2,327,529
California	10	30			14,900,000	25,000,000				5,153,264
	1,900	170			48,511,100,000	10,380,700,000		21,100,000		[1]39,135,327
Grand Totals	339,887	89,482	28,470	986,855,100,000	860,331,100,000	1,314,009,300,000	43,477,800,000	20,721,000,000	604,900,000,000	12,130,805,450

* Mineral Resources, U. S. Geol. Survey, 1917. [1] Miscellaneous colliery consumption, inconsiderable production from some states, etc.

GEOLOGICAL AGE OF THE COAL-BEARING FORMATIONS

As indicated in the table (page 338) the coal seams of the United States range from Lower Carboniferous (Mississippian) to Miocene in age. The eastern part of the country in a general way may be said to carry the Carboniferous, Permian and Triassic coals and the western and Gulf regions the Cretaceous and Tertiary coals. In a general way it may be said also that the coals of the east are of higher grade than those of the west because all the lignite and most of the subbituminous coal lies in the western part of the country or around the Gulf of Mexico. The Carboniferous system is the great coal producer of the east because at the beginning of that period large areas in the eastern part of the continent had but recently emerged from beneath the sea. There were excellent conditions for the development of great swamps on the then existing low lands as there are along the coasts of Virginia and North Carolina today. The western part of the continent was still largely under the sea at that time and there is almost no Carboniferous coal in that part of the country. The age of the coal does not necessarily determine its quality, but, other things being equal, the older the coal usually the higher the fixed carbon because it has been longer subjected to pressure. There is much excellent coal in the West where the younger formations have been sufficiently squeezed to devolatilize it.

The geological age of the coal according to provinces is as follows:

(*a*) Eastern province. Semianthracite occurs in the Pocono of the Mississippian in Virginia, in two small basins southeast of the main field, in Frederick, Pulaski and Montgomery counties. The other coals of the Eastern province all occur in the Pennsylvanian, or Upper Carboniferous, except those in the Atlantic Coast region and a few seams in the Permian. The coals in the Pennsylvanian run through the Pottsville, Allegheny, Conemaugh and Monongahela series. In the southeastern portions of the Appalachian region the coals are to quite a large extent of Pottsville age. For example, those of the famous Pocahontas field of Virginia and West Virginia are of lower Pottsville, those of the New River field of lower and middle Pottsville and much of the coal of Alabama and Georgia is of Pottsville age. This formation carries some coal throughout the whole Appalachian region but outside of the districts mentioned it is, as a rule, not an important producer. The other formations,

especially the Allegheny and Monongahela, carry important coals throughout the region with the exception that the latter formation is not important in the southern part of the field. The Permian carries coal in Pennsylvania, Ohio and Maryland. In the Atlantic Coast region of Virginia and North Carolina the coal is Triassic in age, this being the only coal of that age in the country.

(*b*) Interior province. The coals are all Pennsylvanian, the most widespread formations being the Pottsville and the Allegheny.

(*c*) Gulf province. The coal is of Upper Cretaceous and Eocene age.

(*d*) Northern Great Plains province. The coals in this province range from the Kootenay of the Lower Cretaceous, around the Black Hills, to the Fort Union of the Eocene, in which the bulk of the lignite occurs. There is much difference of opinion among geologists as to whether most of the coal occurs in the Cretaceous or in the Tertiary as the dividing line between the two systems is in many places not distinct. In the Dakotas all the important coal seams, which are almost entirely lignite, are of Eocene age, but there is a little coal in the Lance formation of the Upper Cretaceous. In Montana the coal runs from Jurassic through Lower Cretaceous and Upper Cretaceous to Eocene, very little of it being Jurassic. The Wyoming coals are Lower and Upper Cretaceous and Eocene and those of Colorado are mostly in the Montana series of the Upper Cretaceous with important beds in the Laramie and a little in the Dakota series. Those of New Mexico are also of Upper Cretaceous, (Montana) age with the exception of a very small area of lower Pennsylvanian.

(*e*) The Rocky Mountain province carries coals from Lower Cretaceous to Miocene in age. In addition to the states mentioned under the Northern Great Plains province, Arizona contains Upper Cretaceous coals; those of Utah are mostly in the Montana and Colorado series of the Upper Cretaceous, and some lignite occurs in the Eocene. In Idaho the coal is of Upper Cretaceous and Eocene ages.

(*f*) In the Pacific Coast province the coals are chiefly Eocene in age but small areas are Miocene.

PLATE XIII

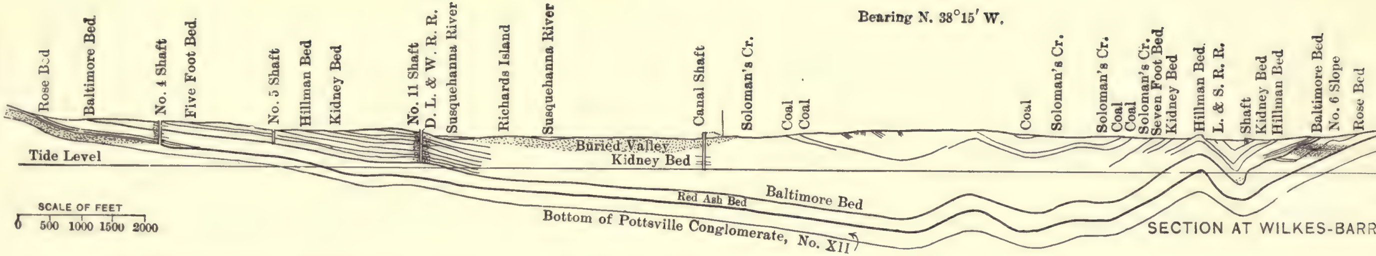


FIG. 1. — Section through the Northern Anthracite field at Wilkes-Barre, showing the buried valley. (After H. H. Stoek, U. S. Geol. Survey.)

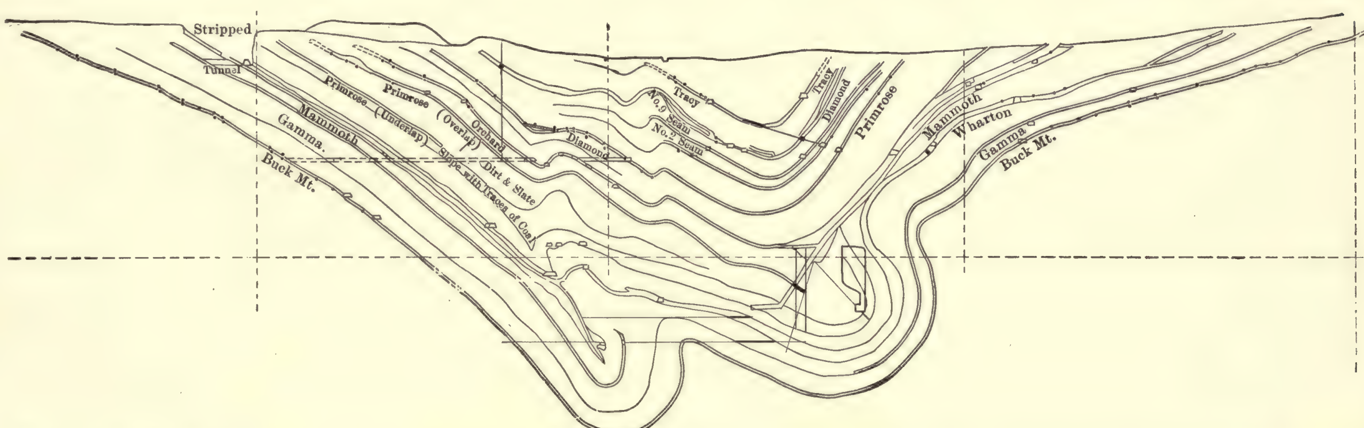


FIG. 2. — Section through the Eastern-middle field at Hazleton showing the very complicated nature of the structure compared with that near Wilkes-Barre.

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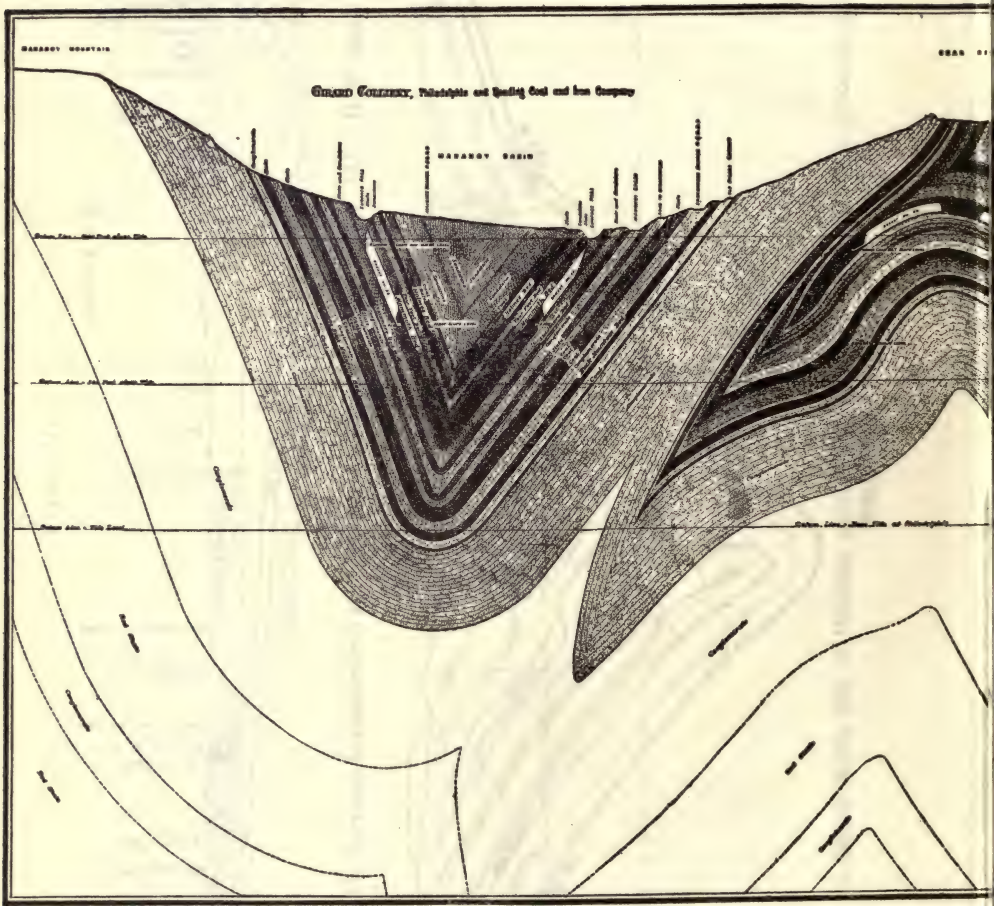
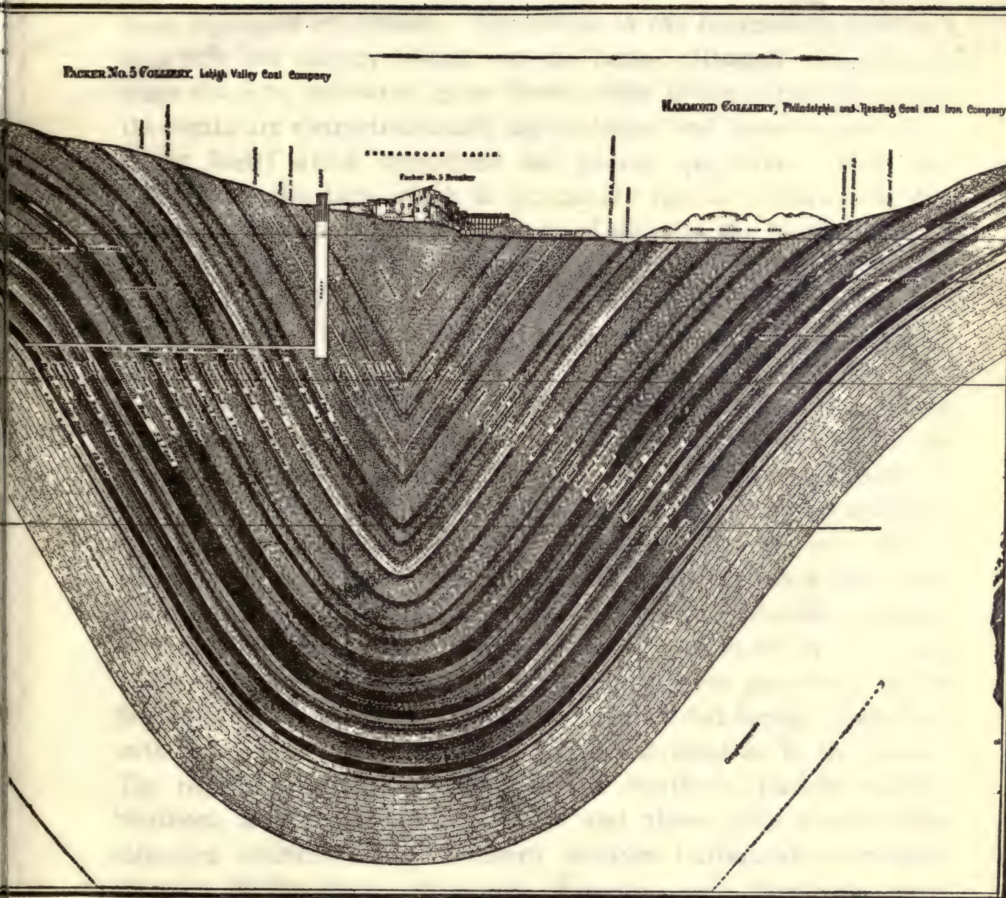


PLATE XIV. — Structure section through the Mah



and Shenandoah basins. (By courtesy of J. Bevan.)

THE COAL FIELDS OF THE VARIOUS STATES[1]

Eastern Province

Pennsylvania.[2] — Pennsylvania contains the anthracite region in the east and the bituminous fields in the west and north-central parts of the state. These two areas were originally connected but they have been separated by erosion. The strata in the bituminous fields are as a rule but slightly folded and the faults, although numerous in some districts, are not of great throw, while in the anthracite region the strata are characteristically highly folded and there are extensive thrust faults which complicate the mining operations. There are some anthracite beds which lie practically flat for considerable distances. Such are, for example, some of those in the Northern basin around Scranton and Wilkes-Barre. These have, nevertheless, been subjected to great pressure but the strata have resisted buckling and the pressure has been transmitted to the coal seam changing the coal to anthracite.

Anthracite region: In the anthracite region the coal lies almost entirely in the synclines as it has been protected from erosion by the Pottsville conglomerate, or as it is often called, Millstone grit, and the Pocono sandstones. These formations are brought up in the anticlines between the basins and between these formations the red Mauch Chunk shale and sandstone makes a distinct horizon-marker and indicates the lower limit of all coal. Usually the Pottsville conglomerate marks the base but a few seams have been found in it. Some of the synclines are probably of great depth; over 4000 feet, in the Southern field. Mining has not so far been carried beyond 2200 feet, with the deepest shaft only 1850 feet, but it must be in the future. The region is usually divided into the Northern, Eastern-middle, Southern and Western-middle fields and these fields contain the following districts. The Northern includes Carbondale, Scranton, Pittston, Wilkes-Barre, Plymouth, Kingston and Nanticoke, these making up the Wyoming trade region. The Eastern-middle field in-

[1] For special comprehensive reports see: 22nd Annual Report, U. S. Geol. Survey, Part III, 1902; The Coal Catalog, E. N. Zern, Editor, Keystone Consolidated Publishing Co., Pittsburgh, 1918; The Coal Fields of the United States, with map, by M. R. Campbell, U. S. Geol. Survey; Coal, by E. W. Parker, Mineral Resources of the United States, 1910.

[2] Second Geological Survey of Pennsylvania; County Reports and Geologic and Topographic Survey Commission reports. Also 22nd Annual Report, U. S. Geol. Survey, The Pennsylvania Anthracite Coal Field by H. H. Stoek.

cludes the Green Mountain, Black Creek, Hazleton, Beaver Meadow, and Panther Creek districts, these making up the Lehigh trade region. The Southern field includes the East Schuylkill, West Schuylkill, Lorberry and Lykens Valley districts, while the Western-middle field embraces the local districts of East Mahanoy, West Mahanoy and Shamokin. The last two fields are comprised in the Schuylkill trade region.

The structure of the region is illustrated by the accompanying sections (Pls. XIII and XIV) and the names of the seams and their relations to one another are also indicated. The anticlines lie in a general direction of about N. 70° E. and as a rule the folds are steeper on the northwestern side of the anticline than on the opposite side since the thrusts producing them came from the southeast. The thickest seam is the Mammoth which reaches 50 to 60 feet of comparatively clean coal and in some places is doubled by folding so that over 100 feet of coal occurs in a stripping. Since the cover over this and some of the other seams is so thin much coal is mined by stripping off the cover and digging the coal with steam shovels. The depth of the cover removed varies from almost nothing to 90 feet, although one stripping will reach almost 200 feet in depth under exceptional conditions. This is at Locust Mountain.

The best-known seams in the various fields are as follows: In the Southern field there are the six Lykens Valley seams in the Pottsville conglomerate, No. VI being the lowest, and three of these beds are found also in the Western-middle field. They vary from thin unworkable seams up to about 11 feet in the Western-middle field. There are no workable seams in the Pottsville in the other two fields.

The lowest bed in the Coal Measures proper is the Buck Mountain bed of the Southern, the Western-middle and Eastern-middle fields. This bed is thickest in the Western-middle field and it probably corresponds to the lowest split of the lowest Red Ash bed in the Northern field. It runs between 3 and 19 feet in thickness. Between the Buck Mountain and Mammoth seams in the Southern field there is the Skidmore bed; in the Western-middle field there are the Seven-foot and Skidmore beds and in the Eastern-middle field the Gamma bed, the Wharton bed and the Parlor bed.

In the Northern field the lowest workable beds are the three Red Ash or Dunmore beds, also known as the Powder Mill and Clifford

beds. Above the Dunmore beds lie the Ross or Clark seam, and the Twin beds, followed by the two splits of the seam known as the Mammoth in the other fields. In this field this seam is known as the Baltimore, Pittston, Fourteen-foot, Big Bed or Grassy Island bed. Above this big seam lie the Rock bed and the Diamond bed, each about 3 feet thick, followed by the Hillman or Olyphant No. I, running up to about 15 feet in thickness. Above this seam is the Kidney, Diamond or Olyphant No. II which probably corresponds to the Diamond beds of the southern fields. It is about 5 feet thick in this field. The Abbott and Snake Island beds lie above it.

In the Eastern-middle field the Mammoth bed which is here around 58 feet thick is the highest bed of importance and it is stripped a great deal. In the Western-middle field there are the Holmes bed, the Primrose bed, the Orchard beds, the Diamond beds and the Tracy beds, lying above the Mammoth seam which is here about 60 feet thick.

In the Southern field the Mammoth seam has a number of splits making up a total of about 120 feet of coal and partings. The seams lying above the Mammoth bed are practically the same as those just mentioned for the Western-middle field with the addition of the Clinton beds. About twenty different beds have been worked in this field.

It has been estimated that over 80 per cent of the coal in the Wyoming basin and approximately 75 per cent of that in the other fields is marketable. The Pennsylvanian rocks are very thick in the Southern field, the Pottsville conglomerate varying from 1100 to 1475 feet in thickness and the other formations making up 2500 feet more. In the Western-middle field about 1200 feet of measures remains, and in the Northern field a maximum of 2200 feet is found in the deep basin between Nanticoke and Wilkes-Barre. The average thickness for the Pottsville conglomerate and the Coal Measures respectively, in the various fields is placed at the following figures: Northern field 225 and 1800 feet; Western-middle 850 and 1000 feet; Eastern-middle 300 and 700 feet, and Southern 1200 and 2500 feet.

An interesting feature in the Northern field is the buried valley between Pittston and Nanticoke in which a large stream flowed before the glacier passed over the region. When the glacier pushed

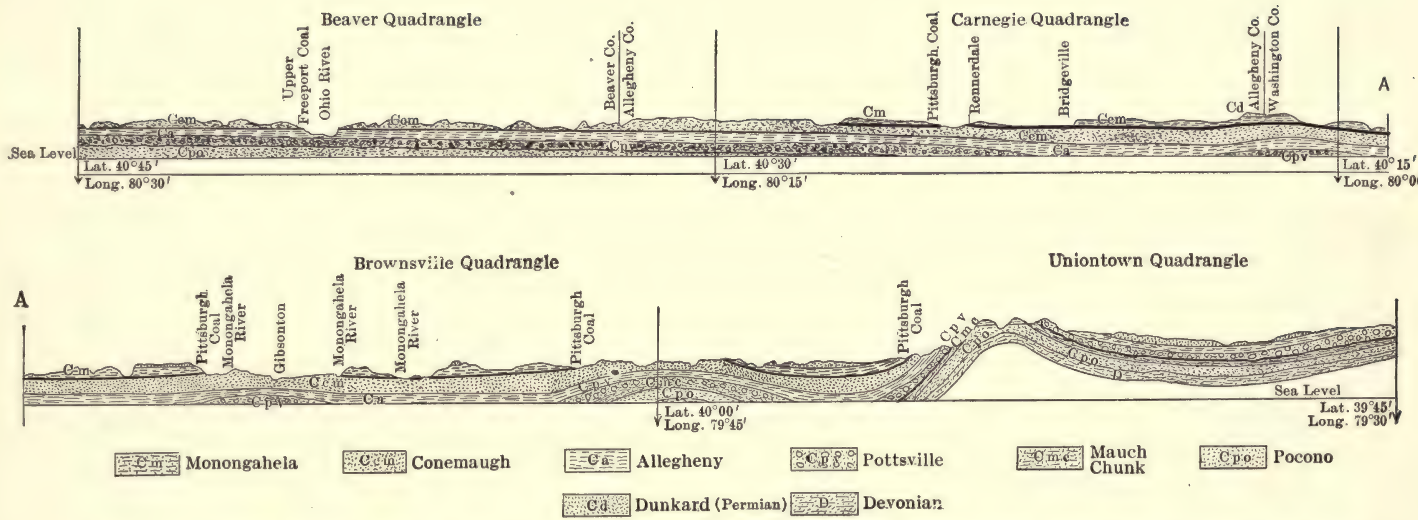


FIG. 116. — Structure section through Beaver, Carnegie, Brownsville and Uniontown quadrangles in the southwestern portion of the Pennsylvania bituminous region.

across the valley in the Pleistocene epoch the valley was filled up and since the glacier melted away the Susquehanna River has made a new channel for itself. It has also been suggested that this valley may have been caused by glacial erosion. Since this pre-glacial valley is filled with débris which holds much more water than the solid rock, it is naturally a menace in mining operations and it has been pretty carefully mapped out.

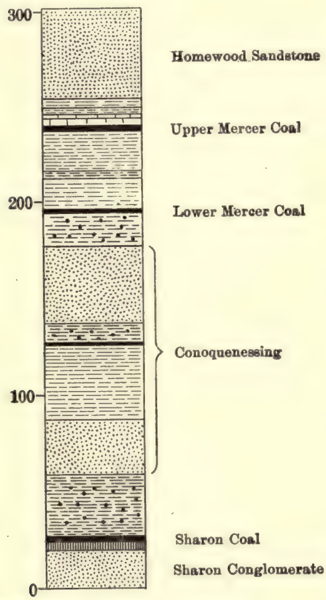


FIG. 117. — Section of the Pottsville in Mercer County, Pa. (After I. C. White, U. S. Geol. Survey.)

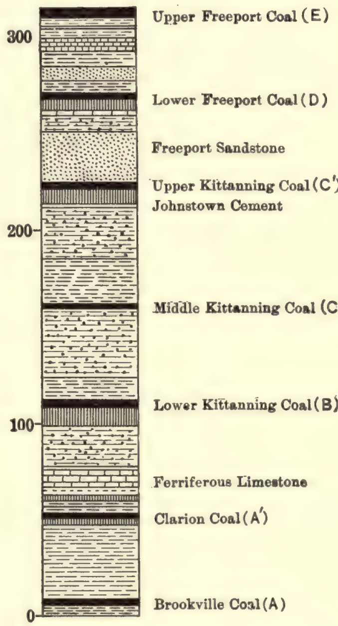


FIG. 118. — Columnar section through the Allegheny formation on the Allegheny River, Armstrong County, Pa. (After D. White, U. S. Geol. Survey.)

Pennsylvania produces almost all the anthracite mined — considerably over 99 per cent — in the country. Anthracite was discovered by the earliest settlers about 1762 and used by smiths and for local purposes for a number of years before active mining began. The records of shipments begin about 1805, but coal is said to have been shipped during the Revolutionary War. At first the people in the towns would have nothing to do with it as they were skeptical regarding its value as a fuel.

The Bernice field of Sullivan County is regarded by some as part of

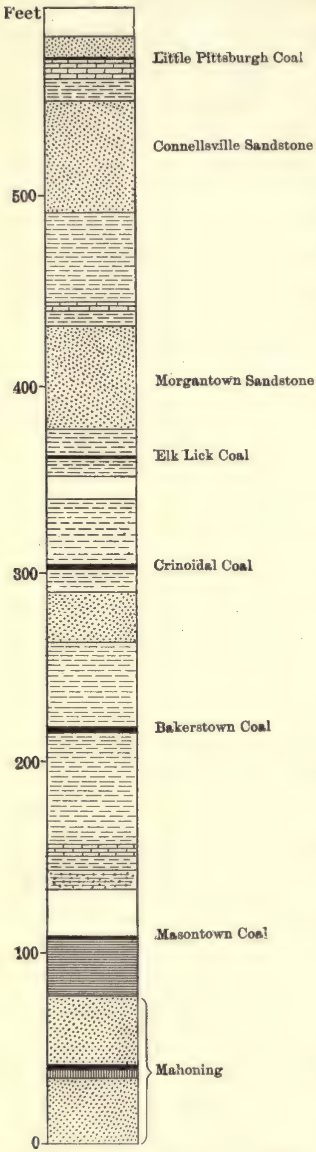


FIG. 119 — Columnar section through the Conemaugh formation on Dunbar Creek, Fayette County, Pa. (After I. C. White, U. S. Geol. Survey.)

the anthracite region and the coal is put on the market as anthracite although it is more strictly semianthracite. It marks the transition from the anthracite region to the bituminous fields farther west.

Bituminous region:[1] The bituminous fields of the state cover 14,200 square miles and while the southeastern border of the area has suffered a good deal of compression where the intensive folding found farther east dies out, the beds for the most part have gentle dips and the coal occurs in a large number of roughly parallel synclinal basins. The Broadtop field in Huntingdon and Bedford counties is a remnant of the Coal Measures folded down into the mountains in that locality and it is more disturbed than most of the other bituminous fields. Owing to the greater amount of folding which the eastern portion of the bituminous area has suffered, much of the coal is semibituminous in character and the Clearfield district is noted for its "Smokeless coal" of this variety.

The coals occur chiefly in the Allegheny and Monongahela series of the Coal Measures, between 40 and 50 per cent of the coal mined coming from the former series. The Pottsville (Fig. 117) contains the Sharon and Mercer coals mined in restricted areas. The Allegheny (Fig. 118) is about 300 feet thick on the average and contains the Brookville, or

[1] White, D., and Campbell, M. R., The bituminous coal fields of Pennsylvania. 22nd Annual Rept. U. S. Geol. Survey, Pt. III, 1902. Also White, U. S. Geol. Survey, Bull. 65.

A coal, the Clarion or *A*[1], the Lower Kittanning or *B*, the Middle Kittanning or *C*, the Upper Kittanning or *C*[1], the Lower Freeport or *D* and the Upper Freeport or *E*. The Brookville coal is worked in many places in the eastern counties of the bituminous fields and the Clarion coal is of workable thickness in numerous localities. The Lower Kittanning is usually less than 4 feet thick but it is uniform in distribution and character. It is also known as the Miller seam. It is a valuable coal in at least eleven counties. The Upper Kittanning is characterized by a large amount of cannel coal in Beaver and Clearfield counties. The Middle Kittanning is not relatively important as it is thin and in many places dirty. The Upper and Lower seams are well known for coking, domestic, gas-producing and other purposes. The lower Freeport or Moshannon seam is a well-known seam, especially in Clearfield, Jefferson, Indiana, Cambria and Center counties. This coal is adapted to almost all varieties of uses. The Upper Freeport extends over a large area but it varies greatly in thickness and quality.

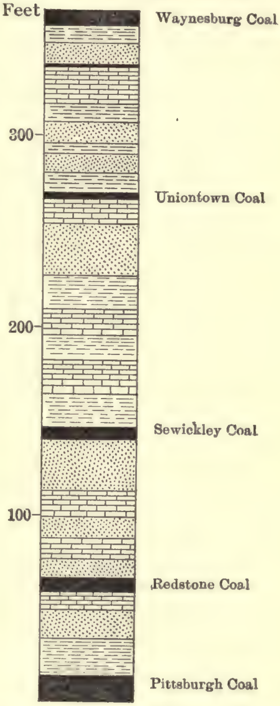


FIG. 120. — Columnar section of the Monongahela formation in Fayette County, Pa. (After Stevenson, U. S. Geol. Survey.)

The Conemaugh series (Fig. 119) carries several seams such as the Berlin, Bakerstown and Coleman but they are comparatively unimportant.

The Monongahela series (Fig. 120) contains the famous Pittsburgh seam and the Redstone, Sewickley and Waynesburg seams. The former seam occurs in the southwestern portion of the state in Greene, Washington, Westmoreland, Fayette, Allegheny, Somerset and Indiana counties. It runs from 4 to 9 feet in thickness and averages about 7 feet over an area of between 2000 and 2500 square miles. The coal of this seam is excellent for a great variety of uses. It has been the famous coking coal of the Connellsville district, and Westmoreland County furnishes one of the best of gas coals from this seam.

The Redstone seam is about $3\frac{1}{2}$ feet thick. It is mined in a number of places in the southwestern counties, but on the whole it is not very important. The Waynesburg seam is mined in Westmoreland, Washington and Greene counties. It is about 3 feet thick on the average but locally it runs 6 feet, and in places it is a block coal. The coal is frequently bony.

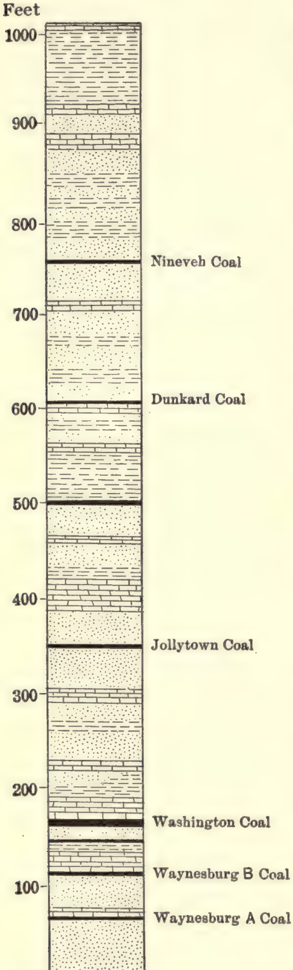


FIG. 121. — Columnar section through the Dunkard formation in Greene County, Pa. (After Stevenson, U. S. Geol. Survey.)

The Dunkard series of the Permian system carries the Washington seam which is worked to some extent in Washington and Greene Counties. It may reach 10 feet in thickness but, like the Waynesburg seam, it carries much rock.

Rhode Island.[1] — The coal in this state is interesting chiefly because of the fact that it has been so squeezed and broken that some of it has been turned into graphite, and therefore does not burn. The proportion of fixed carbon is so high compared with the volatile matter that combustion will not take place in some of the coal. The coal is also very high in ash, much of it running 30 per cent or more. It has been mined intermittently.

Ohio.[2] — Many of the seams mined in southwestern Pennsylvania continue into Ohio. They are all bituminous. In the Pottsville formation (Fig. 122) there are in ascending order, Sharon, or No. 1, the block coal; Quakertown or No. 2; and Lower Mercer or No. 3. Of these the Sharon, which is about 3 feet thick, is the only one of much importance although the others are mined in certain areas. The Sharon has been mined in limited areas, as

[1] Ashley, G. H., Rhode Island Coal. U. S. Geol. Survey, Bull. 615, 1915.

[2] Bownocker, J. A., The coal fields of Ohio, with map. U. S. Geol. Survey, Prof. Paper 100-B, 1917. Also, Bull. 9, Fourth series, Ohio Geol. Survey, 1908.

around Massillon and Jackson. This coal is largely exhausted. It is characterized by coatings of calcium carbonate on the joints, known as "white cap." The sulphur is very low and the coal has been used raw in the blast furnaces in making pig iron. The Quakertown bed, also known as the Wellston or Jackson Hill bed, supplies good coal for domestic and steam purposes, and in Jackson County where it is mined most it runs about 4 feet in thickness. The Lower Mercer, or No. 3 and the Upper Mercer or No. 3*a*, are unimportant. They are characterized by lying under thin limestones which go by the same name. The Upper Mercer is also known as the Bedford cannel and in Coshocton County it reaches a thickness of about 9 feet of which 5 feet is cannel.

The Allegheny series contains the most widely extended and best beds of the state. The seams in ascending order are the Brookville or No. 4, the Clarion or No. 4*a*, the Lower Kittanning or No. 5, the Middle Kittanning or No. 6, the Lower Freeport or No. 6*a* and the Upper Freeport or No. 7. The Brookville seam runs from 2 to 4 feet in thickness and it is not extensively mined as it is impure and thin over large areas. The Clarion bed lies under the Vanport, or Ferriferous limestone, which is a good horizon-marker. It is of comparatively little value. The Lower Kittanning is not of great importance but it is mined and a very important bed of clay lies beneath it. The Middle Kittanning is regarded as one of the most important in Ohio. It usually runs around 3 to 4 feet in thickness; it is high in sulphur in many places but is widely extended. In the Hocking Valley field what is known as the Jumbo "fault" causes much difficulty in mining. It is not a fault but an old "cut-out" where a stream has washed away the vegetal matter and deposited sand and mud in its place. The Lower Freeport is of little commercial importance except around Steubenville, while the Upper Freeport is a very important seam. The coal breaks down readily and is not suitable for transportation but it is a good steaming fuel. Its maximum thickness is about 7 feet. Lying between the Upper Freeport and the Pittsburgh bed is the Conemaugh series, about 350 to 500 feet thick. It contains the Mahoning, Mason and Anderson seams, the latter being equivalent to the Bakerstown of Pennsylvania, but they are thin and little worked.

The Monongahela, or Upper Productive Measures, contains three

seams of importance: The Pittsburgh or No. 8 at the base; the Redstone or Pomeroy, or No. 8*a*; and Meigs or No. 9. The Pittsburgh is not as extensive or of as good quality as the Middle Kittanning. It occurs in the three fields, Belmont County, Federal Creek and Swan Creek. The coal is used mostly for steam and domestic purposes. It runs about 6 feet in thickness with several clay partings in many places, and thin limestones occur in the shales of the roof. In some areas, as in Jefferson County, the coal is mined with steam shovels. The Pomeroy was for years regarded as the Pittsburgh bed of Pennsylvania but it is now known to be the equivalent of the Redstone. It runs from 2 to 5 feet in thickness and is high in ash. The Meigs Creek is an important bed but in many places it is irregular. It is the equivalent of the Sewickley seam of Pennsylvania. The coal is used mostly for steam and domestic purposes. It is like many of the Ohio coals in being high in sulphur, and bands of pyrite frequently occur. In the Dunkard group of the Permian there are several thin seams but they are not of importance.

Maryland.[1] — The coals of Maryland occur in the following five basins: Georges Creek, Upper Potomac, Castleman, Upper Youghiogheny and Lower Youghiogheny, all confined to Allegheny and Garrett counties. The Georges Creek basin is the most prominent producer with most of the remaining coal coming from the Potomac basin. The coals are mostly semibituminous. The following seams are recognized: Brookville, Clarion, Lower Kittanning, Upper Kittanning, Lower Freeport and Upper Freeport, in the Allegheny series. Those of the Pottsville are unimportant. In the Conemaugh the Bakerstown seam occurs and is of some importance. The Monongahela carries the Pittsburgh seam and the Upper Sewickley, also known as the Gas coal. The Pittsburgh seam or " Big Vein " has been the main source of the coal of the state but the other seams are being developed more and more in recent years. This seam runs about 8 feet in thickness although in the southern part of the field it reaches 14 feet. The coal is massive and breaks down in large blocks. It furnishes a famous bunkering and steaming coal and can be coked, but it is not used to any extent for the latter purpose.

West Virginia.[2] — Many of the coal seams of Pennsylvania, Ohio

[1] Clark, W. B., Maryland Geol. Survey, Vol. V, 1905.

[2] White, West Virginia Geol. Survey, Vol. II, 1903 and Bull. 2, 1911.

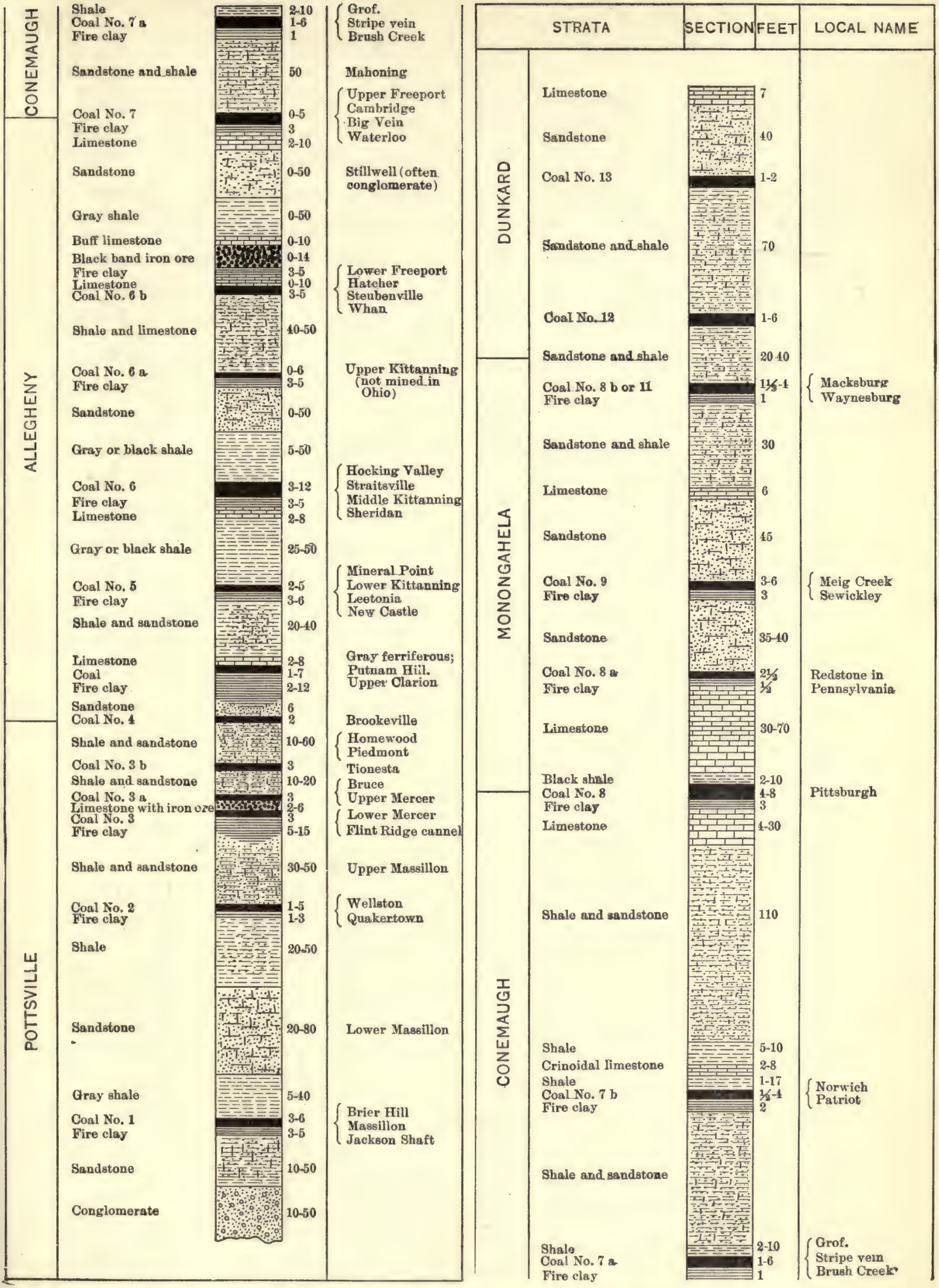


FIG. 122. — Columnar section of the Carboniferous formations in Ohio. (After Hazeltine, U. S. Geol. Survey).

and Maryland extend into West Virginia, the main one being the Pittsburgh bed. This state is the second most important producer in the Union and her production is increasing rapidly. The main fields of West Virginia are the Fairmont or Clarksburg, the Piedmont or Elk Garden in the northern part of the state, and the New River, Kanawha and Pocahontas fields in the southern part. The Piedmont field is a narrow field lying in the Potomac basin to the east of the others and it carries semibituminous or "smokeless" coal in the following well-known veins: Pittsburgh, or "Big Vein," Thomas, or Upper Freeport, and Davis, probably Upper Kittanning. The Pittsburgh seam reaches a thickness of 11 feet.

Much of the coal from West Virginia, especially in the southern part of the state, occurs in the Pottsville formation and this formation seems to increase in relative importance in the states to the southwest. The seams in the Pottsville in ascending order are the famous Pocahontas seams, Nos. 3, 4 and 6 of the Pocahontas field. Pocahontas No. 3, known as the Thick seam and lying at the base of the Pottsville, reaches 12 feet in thickness though usually running around 6 feet. Pocahontas No. 4 also runs about 6 feet in thickness and No. 6 is not mined to any great extent. It runs up to 5 feet in thickness. The coal of this field is semibituminous, low in ash and sulphur and therefore suitable for mixing with high volatile coals in by-product ovens. It is a wonderful steam coal. In the New River field the lower and middle Pottsville, known as the New River group, carry the Fire Creek, Beckley, Welch, Sewell and Iaeger seams. Of these the Sewell, varying from 2 to 5 feet, the Beckley about 4 feet and the Fire Creek, 3 to 7 feet, are the most important and most largely mined seams. The coal is semibituminous and coking. In the Kanawha field the group of rocks named after the field is of Upper Pottsville age. The seams are the Eagle, Powellton, Gas, Alma, Cedar Grove, Chelton, Winifrede, Coalburg and Stockton. Of these the Eagle, Gas, Cedar Grove, Coalburg and Stockton are important. Some of these beds reach 12 feet in thickness. The Cedar Grove and Stockton carry cannel and the Coalburg and Stockton are known as the splint coals. The coal of the Kanawha field is bituminous to semibituminous. It is coking, some of it is excellent gas-producing coal, and in general it is of high grade.

In the Allegheny series the Lower Kittanning, Lower Freeport and

Upper Freeport seams are found. The first seam is important in three of the fields and reaches 7 feet in thickness. The Upper Freeport is important in the northern part of the state, in places reaching 9 feet. These coals are good steaming and by-product coking coals, used chiefly for mixing with other types. In the Conemaugh the Bakerstown seam is worked to some extent in the Potomac basin.

In the Monongahela the Pittsburgh, the Redstone, Sewickley and Waynesburg seams all occur in the northern fields only, the Pittsburgh in the Fairmont, Panhandle and Piedmont fields. The Pittsburgh seam averages 8 feet 6 inches, of which 7 feet are mined. It is a lump coal, high in sulphur in places, but much used in beehive coking where sulphur is low. It is a high grade bituminous steaming and domestic fuel. The Sewickley is an important seam reaching 10 feet in thickness. It is a good coal, containing much mineral charcoal. The Waynesburg is mined but little.

Virginia.[1] — Virginia is said to have produced the first bituminous coal in the United States, coal having been discovered in 1700, mining begun in 1787 and shipments make in 1789. This coal occurs in the Atlantic Coastal region in rocks of Triassic age and in a synclinal basin much cut by faults and so intruded by igneous rocks that in places the coal has been changed to natural coke. The coal is bituminous to semianthracite and some of it is of high grade. Some seams are very thick, but mining conditions are bad and mining has only been carried on intermittently. This field extends into North Carolina.

The other fields of Virginia are the Pocahontas or Flat Top field, a continuation of the field of the same name in West Virginia, and the Big Stone Gap field which extends into Kentucky. In Frederick County there is a small isolated field, and another in Pulaski and Montgomery counties. In these fields the coal is of Mississippian age, and in the Pocono formation. This is geologically the oldest coal in the country. The coal is semianthracite to anthracite and of good quality. It is mined when thick enough to work, and some seams reach 4 feet or more in thickness.

[1] U. S. Geol. Survey, 19th Annual Rept., Pt. II, p. 393, 1898, Geology of the Richmond Basin, Virginia, by N. S. Shaler and J. B. Woodworth; also Bull. 111, 1893, Geology of the Big Stone Gap Coal Field of Virginia and Kentucky by M. R. Campbell; Mineral Resources of Virginia by Watson, Bulls. 9 and 12.

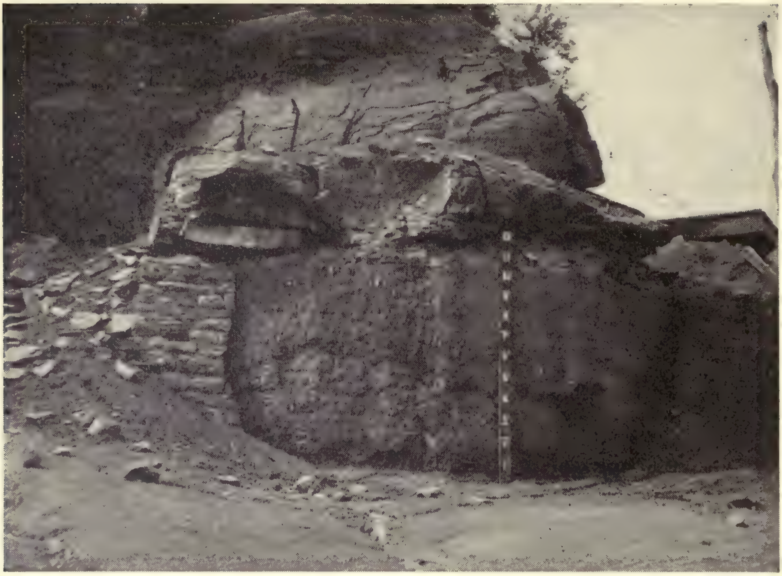


FIG. 123. — Outcrop of the "Big" seam at Pocahontas, Va. with crossbedded sandstone above it. (Photo by H. Ries.)

FIG. 124. —Breaker for semibituminous coal at the Merrimac Mine, Merrimac, Va. (Photo by H. Ries.)

The seams mined in the other fields are, in ascending order, the Darby, Jawbone, Kennedy, Imboden, Lower Banner, Upper Banner and Pocahontas No. 3. The Pocahontas No. 3 is a continuation of this seam from West Virginia and here it is of the same quality and averages about 9 feet thick. The other seams occur chiefly along the extreme western part of the state. The Upper Banner and the Imboden are very important and the latter is a specially good coking coal. The other seams are all mined to a greater or less extent and some of them run as high as 10 feet in thickness. They are Pottsville in age and of bituminous character.

Kentucky.[1] — The coal fields of Kentucky occur along the southeast and the northwest borders of the state, the southeastern portion being included in the Eastern province and the northwestern in the Interior province. The coal-bearing rocks of the southeastern part of the state are Pottsville and Allegheny. The Pottsville is about 500 feet thick and carries a large number of coal beds. There are about a dozen workable beds, the main ones being the Flag, Fire Clay, Hazard, Keokee, Leonard, High Splint, Dean, Harlan, Miller's Creek and Elkhorn. These seams range in thickness up to about 9 feet. The Keokee is equivalent to the Darby seam of Virginia. The High Splint as the name indicates, carries splint coal, an important gas coal. The coals are bituminous. Some seams are good coking and particularly good gas coals. There is a good deal of cannel coal in this field forming seams, or bands and lenses in the bituminous seams.

In the northwestern section of the state the main seams are known as Nos. 9, 11 and 12, of which No. 9 is equivalent to No. 5 of Illinois. No. 9 is the most important producer. It averages about 5 feet in thickness and lies within 300 feet of the surface. In places this seam is badly faulted. No. 11, lying higher up, is more irregular but thicker in places than No. 9, being about 6 feet thick. No. 12 is worked in some areas. The coals are bituminous and higher in volatile matter than those to the east. They are also high in sulphur and ash.

[1] Annual Rept., Inspector of Mines of Kentucky, 1902. Also Ky. Geol. Survey, series 2, Pt. XI, Vol. IV, by Moore; and Bull. 18, 1912 by Fohs. For analyses see Ky. Geol. Survey, New series, Chemical Reports.

Tennessee.[1] — The Tennessee coal beds occur in the following basins: Wartburg, Walden, Sewanee and Cumberland. In the last-named it is said the Coal Measures are over 3000 feet thick and that they contain almost 100 feet of coal. The Wartburg basin has three or four beds which are now worked, one of which, the Briceville, is about 4 feet thick. In the eastern part of the Walden basin the beds are sharply upturned, but for the most part the coals of Tennessee lie quite flat. The best known seams in the state are the Sewanee, Jellico and Coal Creek. The coals are all bituminous and most of them are suitable for steam, domestic purposes and gas manufacture. The Coal Creek coal is used in coking.

Georgia.[2] — Only 167 square miles are underlain with coal in this state and the coal is all of Pottsville age. The Walden basin of Tennessee crosses through Georgia into the Warrior and Blount Mountain basins of Alabama. The Lookout basin extends into Walker County, Georgia. In this basin the coal is of high quality, being semibituminous to semianthracite and low in sulphur. Part of it is coked. The rest of the coal in the state is bituminous.

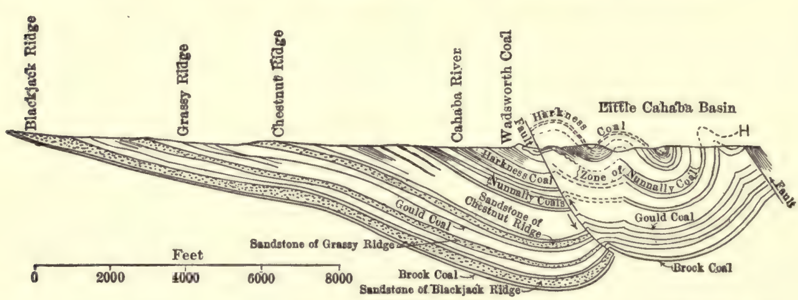


FIG. 125. — Structure section in the northern part of the Cahaba Coal Field, Ala. (By Charles Butts, U. S. Geol. Survey.)

Alabama.[3] — The Coal Measures in crossing from Georgia widen out in Alabama and form four important basins, the Coosa, Cahaba, Warrior and Plateau basins. The Coosa basin is a deep syn-

[1] Hayes, C. W., The Southern Appalachian Coal Field. U. S. Geol. Survey, 22nd Annual Rept. Pt. III, p. 227, 1902. Also Resources of Tennessee I, No. 5, by Ashley.

[2] McCallie, Georgia Geol. Survey, 1904.

[3] Butts, C., The northern part of the Cahaba Coal Field, Ala. U. S. Geol. Survey, Bull. 316, p. 76, 1907. Also reports by McCalley on the Warrior Field, 1900 and by Gibson on the Coosa Field, Ala. Geol. Survey, 1895.

cline of unexplored depth about 60 miles long by 6 wide. It contains a large number of seams. Two seams are worked, the Eureka and the Coal City. This basin is considerably faulted and folded.

The Cahaba basin covers about 350 square miles and is very deep, the coal beds probably extending more than 3000 feet below the surface, (Fig. 125). The thickness of the Coal Measures is usually considered about 5500 feet. There are about ten seams mined and the coal is bituminous and coking.

The Warrior is the most important of the basins. The best known seams are the Pratt and the Mary Lee as they furnish most of the coal mined in the Birmingham district, and this coal furnishes the coke after washing. The Pratt seam in places reaches 16 feet in thickness. Besides these two seams 16 other beds are worked in this basin. The Plateau field is small and undeveloped but it contains many good beds. The coals in Alabama are all of Pottsville age and bituminous in character.

The Interior Province

Michigan.[1] — The coal basin of Michigan contains a comparatively flat-lying, slightly faulted series which includes the Pottsville and Allegheny formations of the Pennsylvanian and which is

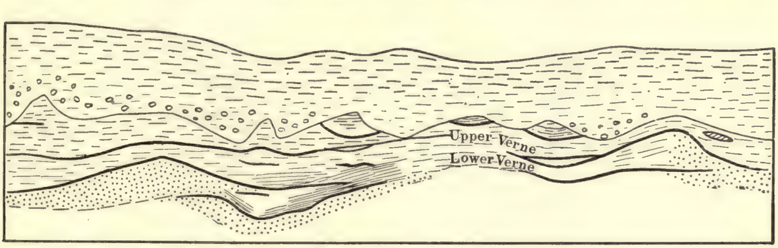


FIG. 126. — Structure section in Bay County, Mich., from the Amelith Mine to the Central and Michigan mines. It shows glacial drift overlying the eroded surface of the Coal Measures. (After Lane, U. S. Geol. Survey.)

overlain by glacial drift. There are seven coal-bearing horizons of significance and these are known as the Lower Coal, Lower Rider, Saginaw, Middle Rider, Lower Verne, Upper Verne and Upper Rider. The seams are very irregular in thickness and character and they change rapidly from place to place (Fig. 126). The coal is of bitu-

[1] Lane, A. C., The Northern Interior Coal Field. U. S. Geol. Survey, 22nd Annual Report. Pt. III, p. 313, 1902. Also Geol. Survey, Michigan, Vol. VIII, Pt. 2.

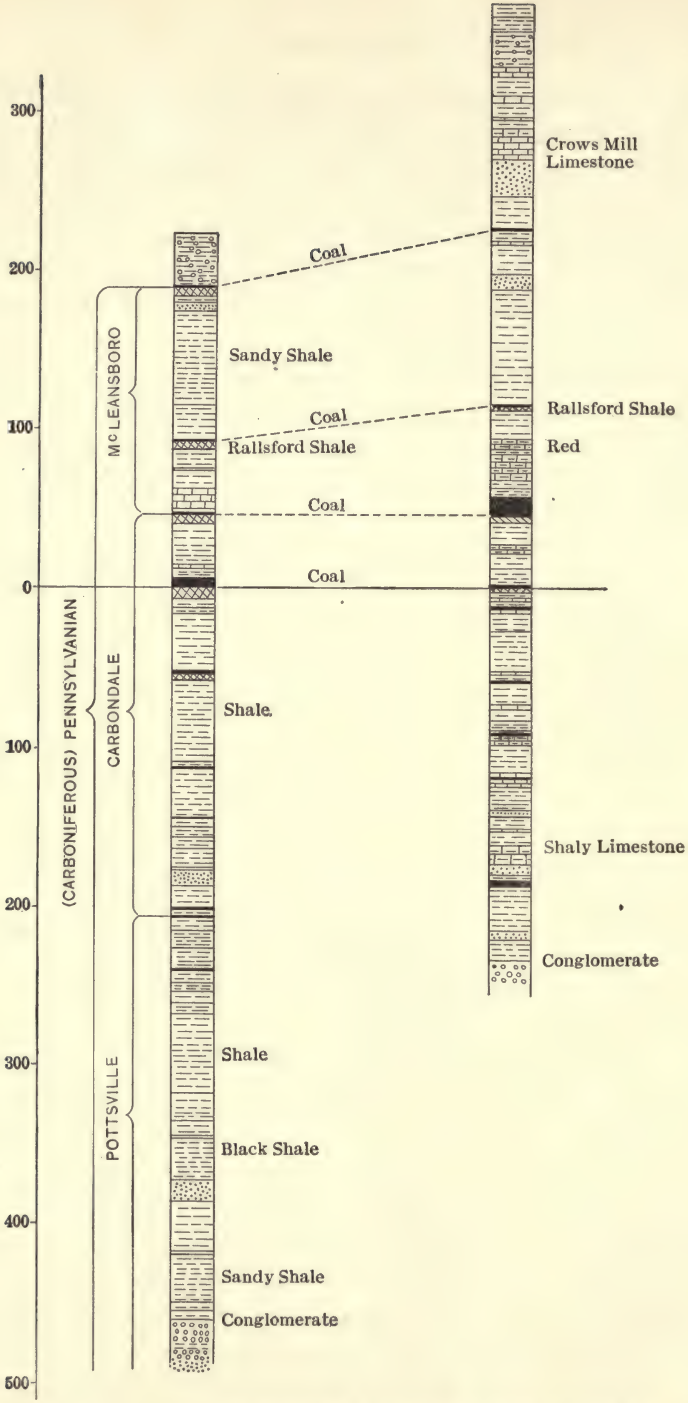


FIG. 127. — Columnar sections of the Coal Measures in Illinois. (Illinois Geol. Survey.)

minous rank, is non-coking and dry and is used for steam, producer gas, domestic, and related purposes.

Illinois.[1] — Illinois has the largest area of Carboniferous coals of any of the states as nearly three-fourths of the state is underlain by Coal Measures. The basin is comparatively flat with from 1500 to 2000 feet of measures near the center. The seams are faulted in many places by small faults and near the Kentucky border the beds are caught in overturned folds and considerably faulted. The fields are covered with glacial drift so that prospecting is often carried on with difficulty, shafts being necessary to reach the coal. The shafts in the state run from 25 feet to 1000 feet in depth but the majority are probably less than 300 feet. The beds as a rule are extensive and persistent. The coals are both coking and dry but the coals which will coke are high in sulphur, the average running around 3 per cent for many of the mines, and they are therefore unsuitable for commercial coke. They are used mostly for domestic, steam and locomotive purposes. Much of the coal is washed and sized. The longwall method of mining is used to a considerable extent in this state.

In geological age the coals are Allegheny and Pottsville. The most important seams are Nos. 2, 5, 6, and 7. No. 1 seam and a few others occur in the Pottsville and are worked in the southern part of the state, No. 1 probably corresponding to the Mercer horizon farther east. No. 2 occurs in the Carbondale formation, which is regarded as equivalent to the Allegheny, and is a very persistent bed averaging around 4 feet in thickness. It is regarded by some as equivalent to the Clarion coal of Ohio and Pennsylvania. In places it contains many sulphur balls. These concretions are also common in No. 5 and in the roof shale above that seam. No. 5 runs about 4 to 5 feet in thickness and is an important seam. No. 6, or the "Belleville" seam, is probably the most persistent in the state, and in the western part is mined to a depth of about 800 feet. It runs from 5 to 6 feet in thickness over large areas and in places it reaches 9 feet. No. 7 is mined around Danville and is from 5 to 7 feet in thickness. It contains much sulphur which can be read-

[1] Ashley, G. H., The Eastern Interior Coal Field, U. S. Geol. Survey, 22nd Annual Report, Pt. III, p. 271; Bulls. 1 to 15, Ill. Coal Mining Investigations, at University of Illinois, also Bulls. 4, 8 and 16, Illinois Geol. Survey.

ily separated by picking and washing. Another higher seam, No. 8, is mined in some localities.

Indiana.[1] — The coal beds of Indiana occur along the western border of the state and the coal is all of bituminous rank. It occurs in the Pottsville and Allegheny formations as in Illinois. Workable coal is found at eight horizons at least and six of these are producing. The main seams are known as the Lower and Upper Block, the Minshall, and seams Nos. 2, 3, 4, 5, 6, and 7. No. 8 is thin. The lower coals, including the Block and Minshall seams, are of Pottsville age and are characterized by being non-coking, pure and dry coals which break into rectangular blocks. The seams usually run about 3 feet in thickness as an average. The other seams are classed as bituminous coals of Allegheny age and they run from 3 to 10 feet in thickness with 5 feet a very common figure and the beds very persistent. The shafts run from 50 to 450 feet in depth for most of the field.

Iowa.[2] — The coal fields lie in the southern and central part of the state and cover about 12,500 square miles. The beds are of lower Pennsylvanian age, as in Illinois and Indiana, and they occur in the Pottsville and Allegheny formations. These are represented by

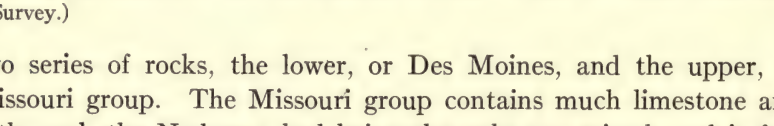


FIG. 128.— Ideal cross-section of the formations in Mahaska County, Iowa, illustrating the character of the Coal Measures in Iowa. (After H. Hinds, Iowa Geol. Survey.)

two series of rocks, the lower, or Des Moines, and the upper, or Missouri group. The Missouri group contains much limestone and little coal, the Nodaway bed being the only one mined, and it furnishes less than 1 per cent of the coal mined in the state. It is 16 to 20 inches thick and fairly persistent. The Des Moines group, although consisting chiefly of shale and sandstone, has a thin limestone bed near the middle. It carries a well-known seam, the Mystic or Centreville bed, which is persistent and extends over into Mis-

[1] Ashley, G. H., Stratigraphy and coal beds of Indiana Coal Field. U. S. Geol. Survey, Bull. 381, p. 9, 1908; also Indiana Dept. of Geol. and Nat. Res., 33d Annual Rept. 1909.

[2] Hinds, Henry, The coal deposits of Iowa. Iowa Geol. Survey, Vol. XIX, 1908.

souri. The lower part of the Des Moines group carries a number of beds and while they locally run up to 10 feet or more the average is about 5 feet in thickness. The seams are characterized by their lack of persistency and their sudden changes in quality. They lie nearly flat and while faults are numerous they are not large. The coal is dry, non-coking, comparatively high in sulphur and used almost entirely for domestic and railroad purposes. The coal field is covered with glacial drift so that there are few outcrops and prospecting is difficult. For this reason little is known about many of the seams. Much of the coal lies 400 to 500 feet below the surface.

Missouri.[1] — The same geological series occur in Missouri as in Iowa, the Pennsylvanian rocks being divided into the upper, or Missouri group and a lower, or Des Moines group. The upper is quite largely a limestone series and carries little coal. Most of the seams occur in the Des Moines group. Those near the base are very irregular and lack persistency while the seams associated with the thin limestone beds higher up in the group are very persistent and comparatively regular. The main fields are the Bevier where the Bevier seam is 3 to 6 feet thick; the Lexington with a seam 14 inches to 2 feet thick which is mined by the longwall method; the Southwestern field; the Novinger field with a seam $3\frac{1}{2}$ feet thick and probably equivalent to the Bevier seam; the Marceline where a 29-inch seam is mined; and the Mendota where the coal lies at about the same horizon as that in the Lexington and the bed is supposed to be equivalent to the Centreville seam of Iowa. It is not mined to any great extent. There are a number of "pockets" of coal lying in isolated areas east of the main field. Some of these are very thick but limited in extent, Parker mentioning one where the coal is 80 feet thick and consists of ordinary bituminous coal and cannel.

The seams of Missouri mostly lie nearly flat and the faults, while numerous, are small. There are many horsebacks, concretions and other obstructions in mining. Owing to the shallowness of the seams in parts of the state, approximately 20 per cent of the annual output is produced by the use of steam shovels. The coals are not high grade as they are high in sulphur, moisture and ash. They are used as domestic and steaming fuels.

[1] Hinds, H., Missouri Bur. Mines and Geol., Vol. XI, 2nd series, 1912.

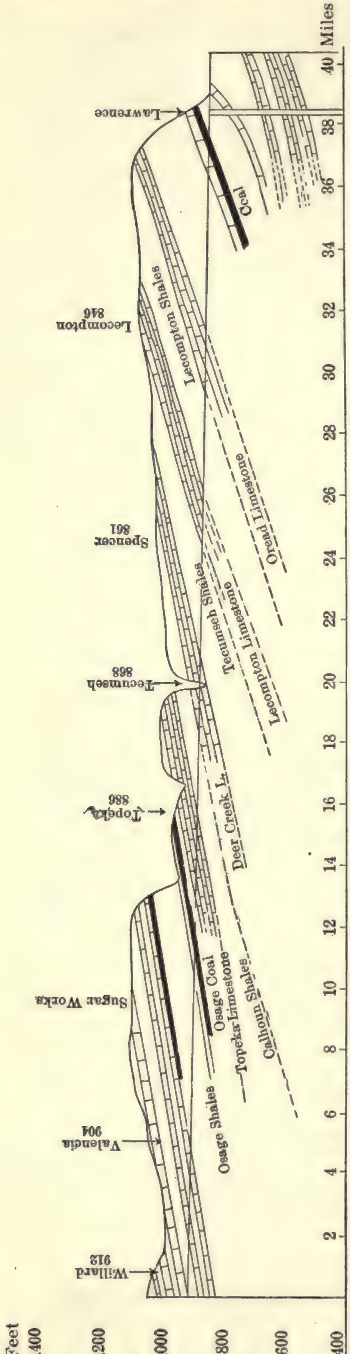


FIG. 129. — Structure section through a portion of the Coal Measures of Kansas. (Kansas Geol. Survey.)

Kansas.[1] — About 20,000 square miles are underlain by Pennsylvanian rocks in this state and it is estimated that nearly three-fourths of the area will prove productive. The field lies in the eastern portion of the state and the most important and best-known localities are in Cherokee and Crawford counties which furnish over 90 per cent of the coal. The geological series are much like those of Iowa only less distinctly marked, with limestone more abundant in the lower series and the coal distributed more widely through the various formations. The thickness of the measures is about 3000 feet and on the whole the beds lie nearly flat, (Fig. 129). The Cherokee seam is the main bed and it varies from 3 to 10 feet in thickness with an average of about 40 inches. This coal is washed and it may then be coked but most of it is used for locomotive and domestic fuel. Much coal is mined by stripping methods where it lies near the surface. The weathered coal from the pits is non-coking because of oxidation. It is used raw in some of the zinc furnaces.

In the Leavenworth district a

[1] Howarth and Crane, Kansas Geol. Survey, Vol. III, 1898. Also the Western Interior Coal Field by H. F. Bain, U. S. Geol. Survey, 22nd Annual Report, p. 339, 1902.

thin seam is mined at a depth of 700 to 1150 feet. This is the only deep mining, according to Parker, which is carried on in the Western Interior field. Another area occurs in the Osage County district where a seam is mined at a horizon about 2000 feet above the Cherokee bed.

A small lignite field also occurs in Kansas with coal of Cretaceous age which is mined for local consumption.

Oklahoma.[1] — The rocks carrying coal in Oklahoma apparently represent most of the Pennsylvanian formations. There are two main fields, the Cherokee and the Choctaw, the latter much the more important. The coals vary from ordinary bituminous to semibituminous. Some of the coals are coking and a number of ovens are operated, but most of the coke is too high in sulphur for iron furnaces. There are about ten workable seams of which the following are the best known: Hartshorne, Dawson, Henryetta, McAlester, Cavanal and Witteville, upper and lower. The Henryetta is the most important seam in the Cherokee field and averages about 3 feet in thickness. The Hartshorne seams run from 2 to 7 feet in thickness and the McAlester coals about 4 feet. The strata are much folded and faulted in parts of the fields, and many of the mines carry considerable gas.

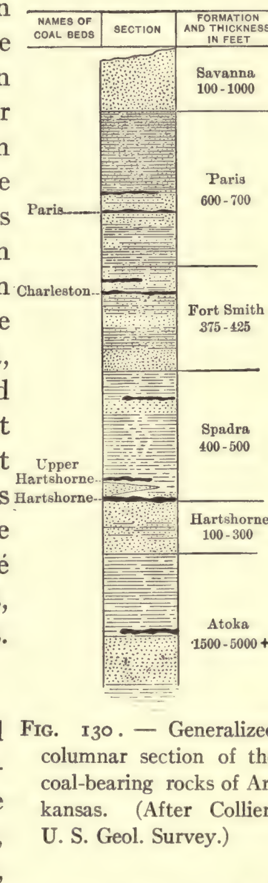


FIG. 130. — Generalized columnar section of the coal-bearing rocks of Arkansas. (After Collier, U. S. Geol. Survey.)

Gulf Province

Arkansas.[2] — The coal beds are well exposed in this field and they have suffered considerable folding, faulting and erosion. They are of Pennsylvanian age, Pottsville to Allegheny, and the coals vary, even in the same seam, from bituminous to semibituminous and semianthracite, the fuel ratio increasing from about 5 on the western side of the field to

[1] Taff, J. A., The Southwestern Coal Field. U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 367, 1902.

[2] Collier, A. J., The Arkansas Coal Field. U. S. Geol. Survey, Bull. 316, p. 137, 1906.

nearly 8 on the east. There are three seams, of which the Hartshorne, corresponding to the seam of the same name in Oklahoma, is the most important. This seam is about 8 feet thick and it supplies nearly all the coal of the state. Other seams which are mined a little are the Charleston, lying about 700 feet above the Hartshorne and the Paris about 1000 feet above the latter seam. There is some lignite lying in the lowlands southeast of Little Rock. It is mined to a small extent but is practically undeveloped. It is of Tertiary age and listed under the Gulf province.

Texas.[1] — There are three fields in Texas with coals of three different ages and grades. One of the fields in the north-central part of the state belongs to the southwestern field of the Interior province. The coal is Pennsylvanian in age and mostly of bituminous rank although there are portions of it which might be more properly classed as subbituminous. The Pennsylvanian is here divided into the following divisions in ascending order: Millsap, Strawn, Canon, Cisco and Albany. The structure is simple, the basin dipping gently northwestward and westward. There are three workable seams, two of which are worked. They are thin, in few places more than 2 feet. No. 1 seam is in the Millsap and the Cisco formation carries two workable beds, one known as No. 7 which is the highest bed worked. The coals are high in sulphur and ash and are therefore used mostly for railroad and other steaming purposes.

The Eagle Pass field is a small one on the Rio Grande and it extends over into Mexico. The strata are considered to be of Upper Cretaceous age and the coal is subbituminous in rank. The beds run from 5 to 6 feet in thickness and dip steeply in parts of this field.

The large lignite field extends across the state from the Sabine River to the Rio Grande. The rocks are of Eocene age and the coal varies from woody lignite to subbituminous grade. The latter occurs in the Laredo field along the Rio Grande where the rocks have been compressed by the uplift of the Sierra Madre Oriental, a little to the southwest, in Mexico. Campbell has pointed out that in the southern part of the state the lignite consists chiefly of trees and other coarse fragments of plants while in the northern part there is a much greater proportion of spores, seeds and other related vegetal

[1] Dumble, E. J., Texas Geol. Survey, 1892. Phillips, W. B., and Worrell, S. H., The fuels used in Texas. Bull. University of Texas No. 307, 1913. (Numerous analyses.)

matter in the coal. The lignite occurs in the three upper divisions of the Eocene at comparatively shallow depths and the beds vary from a few inches to about 25 feet in thickness. Those being mined usually run between 4 and 8 feet, except in Webb County where the coal is subbituminous and the seams mined are less than 3 feet thick. The lignite field belongs in the Gulf province. The known field is much less than the probable field as the seams are largely unprospected. The lignite is largely used for domestic purposes, for steam, and in gas producers.

The Northern Great Plains and Rocky Mountain Provinces

These two provinces are considered together here since many states are included in both of them.

Arizona. — Arizona is not yet a producer and has not been well prospected, but it contains several fields and a large reserve of coal of subbituminous quality. It is of Cretaceous age. The main area is the Black Mesa field, a flat, open, synclinal basin with coal in thin benches. The other field of which something is known is the Deer Creek field in the copper-bearing region of the state. This forms a simple synclinal basin with the rocks greatly broken and the coal of little value in the southwestern part. Two beds of workable thickness running from 24 to 30 inches are reported by Campbell.

New Mexico.[1] — This state contains coal varying in rank from subbituminous to anthracite, the latter occurring where the coal has been locally metamorphosed by igneous intrusions as in the Cerillos field. There are five fields: (*a*) The Raton field of Colfax County, which is an extension of the Trinidad field of Colorado and will be discussed under that state; (*b*) The San Juan River region, including the Gallup and Monero producing districts, and extending into Colorado; (*c*) A little-known area in Valencia, Bernalillo and Sandoval counties; (*d*) The Los Cerillos field in Santa Fé County; and (*e*) The Whiteoaks field in Lincoln County. Outside of the Raton field the coal is practically all subbituminous and all the coals of the state are regarded as of Upper Cretaceous age, chiefly Montana, except in a very limited area near Pecos, carrying lower Pennsylvanian coal.[2] Near Monero the coal is bituminous. Some

[1] Storrs, L. S., The Rocky Mountain Coal Field. U. S. Geol. Survey, 22nd Annual Rept. Pt. III, p. 449. Also U. S. Geol. Survey, Bulls. 285, 316, 381, 471 and 531.

[2] Gardner, J. H., U. S. Geol. Survey, Bull. 381, p. 449, 1908.

of the fields, as for example the Carthage field, are complexly faulted and igneous intrusions are common.

Colorado.[1] — This state is the largest coal producer west of the Mississippi. The fields of the state are as a rule divided into the Eastern, the Park and the Western groups. The Eastern group contains the following fields: Trinidad, Cañon City and South Platte. The Park contains the South, Middle and North Park. The Western group is the largest and includes the Yampa field in the north, the Danforth Hills, White River and Grand Hogback to the north of Grand River, the Glenwood Springs basin, Crested Butte and Grand Mesa just south of the Grand River, Book Cliffs near Grand Junction and the Durango field in the southwestern part of the state.

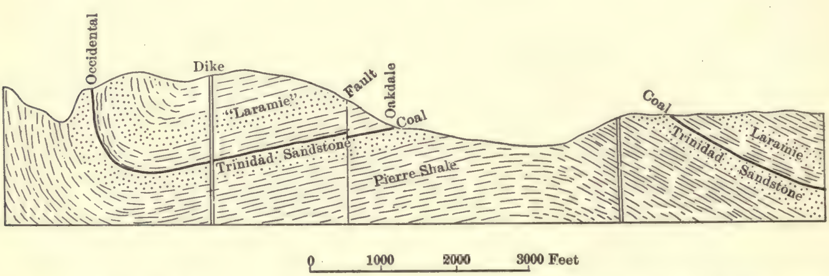


FIG. 131. — Section between Occidental and Oakdale mines, northwest of La Veta. Colo. (After G. B. Richardson, U. S. Geol. Survey.)

The coals are subbituminous in the North Park field and Denver region, partly bituminous and partly subbituminous in the Durango field, partly bituminous and partly anthracite in the Uinta Basin region, and partly subbituminous, partly bituminous, and partly anthracite in the Yampa field. The other fields all contain bituminous coals of varying grades. The anthracite and other high-carbon coals occur in those areas where the coal has been highly compressed or heated by igneous rocks and thus devolatilized. The same seam may carry coal ranging from bituminous to anthracite, the latter near the igneous rocks.

The age of the Colorado coals is mostly Upper Cretaceous, the bulk of the coal occurring in the Mesaverde formation of the Mon-

[1] U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 427. Also Bulls. 297 (Yampa) 316 (Danforth Hills, Book Cliffs and Durango) 317 (Book Cliffs) 381 (Denver Basin, South Park, Colorado Springs, Trinidad) Folio No. 9 (Crested Butte).

tana series. Some is Laramie, a little Dakota and a small amount of Eocene age.

The Trinidad field forms part of the Raton Mountain area which extends over into New Mexico. It is divided into the Trinidad district to the south and Walsenburg district to the northeast. The rocks are of Laramie age and the coal-bearing series varies in thickness from 1500 to 3000 feet. In this field there are as many as eight

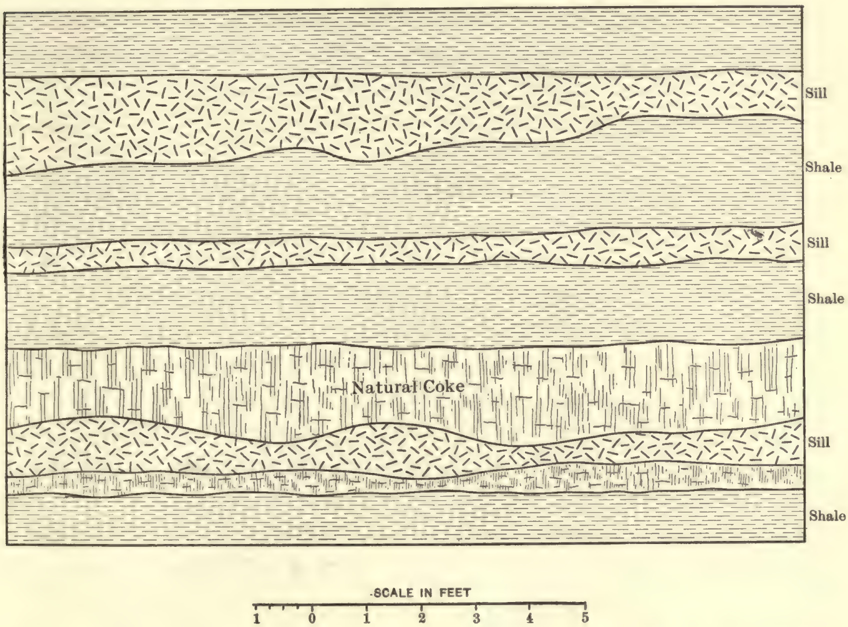


FIG. 132. — Sills of igneous rock in "Laramie" formation and bed of natural coke, in Purgatory Valley, near Trinidad, Colo. (After G. B. Richardson, U. S. Geol. Survey.)

workable beds, varying from 2 to 14 feet in thickness in the lower coal-bearing group of beds, which is about 250 feet thick. These beds lie just above the Trinidad sandstone, and about 500 feet above the sandstone is the middle coal-bearing group carrying at least four seams, 2 to 4 feet thick. Lying about 1000 feet, on the average, above the Trinidad sandstone, is the upper coal-bearing group of shales carrying several seams, but these are unimportant so far as known.

The coal from the Trinidad field is bituminous, that from the northern part being non-coking while that from the southern makes an excellent coke. An interesting occurrence in the Walsenburg district is the niggerhead coal described on page 235. The coal in some of the seams adjacent to igneous rocks forms peculiar spherical structures known locally as " niggerheads " and consisting of quite high-grade coal. Such bodies have been found in a few cases in other fields where igneous rocks have intruded the coal seams. In some places considerable natural coke, or carbonite, has been formed by igneous rocks in the Trinidad field. The structure of this region varies from places where the beds are practically flat and undisturbed to others where they are highly folded, faulted and intruded with igneous rocks.

The Cañon City field is a small one containing bituminous coal in the Laramie formation. The rocks vary from flat-lying to steeply dipping.

The South Platte field includes the counties around Denver and contains subbituminous coal of Laramie age. The beds are comparatively flat except where the strata are more closely folded near the mountains along the western border. The beds are fairly thick in parts of the field and there are four of them in most places. The coal is not of high grade and it is used chiefly for domestic and steam purposes.

The North Park field is reported to carry very thick coals of bituminous rank, some seams as high as 30 feet in thickness, but little mining is done. No mining is now carried on in the South Park field although some mines were operated during the last century.

The Yampa field occupies a large synclinal basin with several minor anticlines and synclines running nearly parallel across it. The strata are in a few places greatly disturbed by faults, but as a rule the faults are of little importance. Most of the basin is not badly folded. The coal-bearing series is the Mesaverde of the Montana series of Upper Cretaceous. This series is about 3500 feet thick and it is overlain by approximately 2000 feet of Lewis and Laramie strata, the Laramie carrying thin beds of coal. The thickness of the seams varies up to about 12 feet. In the Anthracite Range, especially around Pilot Knob, there is some anthracite and natural coke produced by action of the igneous rocks which sometimes affect

the coal for a distance of 50 feet or more. The coals in this field vary from subbituminous to anthracite.

In the Danforth Hills and Grand Hogback fields, which represent part of the Uinta basin region, there is one coal-bearing horizon, the Mesaverde, and this is a distinct ledge-making formation because of the sandstone which it contains. The structure of this region is simple as there are broad basins with minor folds, and faults are not numerous. There are as many as seven seams varying in thickness from 4 to 48 feet, making an aggregate thickness of coal of about 108 feet. Some of these seams are separated by over 1000 feet of intervening strata. The mines through this region are subject to much trouble with explosive gas and spontaneous combustion of the coal.

In the Crested Butte district of the Uinta Basin region considerable anthracite has been formed by igneous activity and both bituminous coal and anthracite occur in this field.

The Durango field, lying in the southern part of the state, extends over into New Mexico in the San Juan River region and of the 73,900 square miles in this field only 1900 lie in Colorado. The coals in this field vary from subbituminous to bituminous. Their geological age is Upper Cretaceous, Dakota, Montana and Laramie. The Mesaverde formation of the Montana carries the best coals, the seams averaging around 5 or 6 feet in thickness. The Dakota coals are not of much inportance, and while the seams in the Laramie are very thick — one reported to be as much as 80 feet — the coal is of an inferior quality to that from the Mesaverde formation. The coal from several localities in the latter formation makes good coke. The structure of the basin is comparatively simple except around Gallup and in the southern end of the basin where the rocks have been highly disturbed.

Utah.[1] — The Uinta Basin region contains the largest area of coal lands in the state and it extends across the Colorado boundary from the Crested Butte district. The beds are deeply covered, going well below 3000 feet in the centre of this basin, and probably out of reach of mining operations. The coals are bituminous and coking. Practically all the coal mined in the state comes from the vicinity of

[1] U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 453. Also, Bulls. 316, 341, 415 and 471.

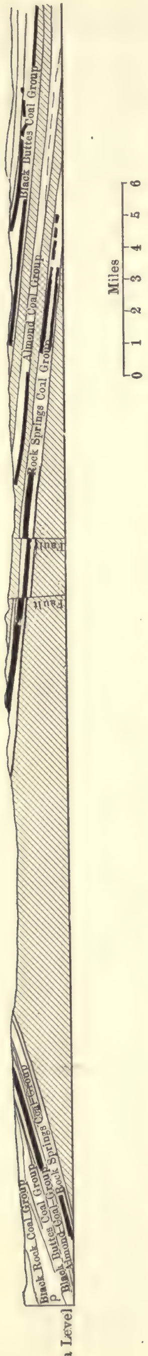


FIG. 133. — Structure section through the northern part of the Rock Springs Coal Field, Sweetwater County, Wyoming. (After Schultz and Lewis, U. S. Geol. Survey, Bull. 341.)

Sunnyside, Castlegate, Winterquarters and Clear Creek. There are about 20 seams in this district, with a maximum individual thickness of about 20 feet. The seams occur in the base of the Mesaverde (Montana) of the Upper Cretaceous. In the Coalville field, which is a small one, two seams running about 7 to 14 feet in thickness are mined. The coal is in the Colorado series.

The other field is the Colob Plateau field which carries a seam in the Colorado series from 1 to 10 feet thick. The coal varies from bituminous to semianthracite and impure anthracite. Because of the closely folded nature of some of the strata much of the coal is of poor quality. In Kane County cannel occurs, and a little anthracite is found in Iron County.

Wyoming.[1] — Wyoming probably contains the second largest resources in coal of any state in the Union, North Dakota coming first. The coals of Wyoming are, however, of higher grade than those in North Dakota since the coal in the latter state is all lignite and that in the former is not below subbituminous, while a considerable amount of it is bituminous in rank.

The following regions are recognized: Black Hills and Powder River regions of the Great Plains province; the Bighorn Basin, Wind River Basin, Green River Basin, Hams Fork region, and the Hanna field, all of the Rocky Mountain province. Of these areas the Powder River region is the largest. It lies between the Bighorn Mountains and Black Hills and runs from the Platte River to the Montana boundary. It represents the extension of the Fort Union region of North Dakota. About 11,000 square

[1] U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 439. Also, Bulls. 225, 260, 285, 316, 341, 381, 471 and 531, and Prof. Paper 56.

miles are underlain with coal beds more than 3 feet thick. The rocks of the field are of Fort Union (Eocene) age and they consist of a lower member of 2500 to 2800 feet of dull-drab, bluish and brown shales and sandstone interbedded with many coal seams. The upper member is subdivided into the Tongue River, Intermediate and Ulm coal-bearing groups. The sandy beds are in many places only slightly consolidated. In the Tongue group which is about 800 feet thick there are at least seven seams ranging from 5 to 32 feet in thickness. The Ulm group is 900 to 1150 feet thick and there is a distinct horizon-marker in the lower part of the group in the form of a shell bed which in some places is directly overlain by a coal seam and in other places separated from it by 30 to 40 feet of sand. There are two workable beds in this group, the Arvade, 5 to 10 feet thick, and the Felix, 6 to 30 feet thick. The Ulm group contains the Lower Ulm or Healy bed, 10 to 15 feet thick. The coal is all lignite and is used for domestic purposes, steam, and producer gas. The structure of the basin is very simple and the beds lie almost horizontal.

The main mining centers of the state are in Uinta and Sweetwater counties. These areas furnish medium-grade bituminous coal. Subbituminous coal is mined in Sweetwater, Carbon, Sheridan, Converse, and Bighorn counties.

The coals of Wyoming vary in age from Lower Cretaceous, of the Kootenay series in the Black Hills region, through the Mesaverde formation in the Montana series of the Upper Cretaceous, to the Fort Union of the Eocene. The older coals are of much higher grade, as a rule. At Cambria a bituminous coal is mined from the Lower Cretaceous rocks. In the Bighorn, Wind River, Hams Fork, and Green River regions the coals are of Upper Cretaceous (Montana and Laramie) and Eocene age. They vary from lignite through subbituminous to bituminous and are non-coking. They are used for domestic purposes, steaming and producer gas.

North and South Dakota.[1] — North Dakota probably has the largest reserve of coal of any state in the Union. The coal of the Dakotas is, however, all lignite. It is estimated that nearly 35,000 square miles in North Dakota and 11,000 in South Dakota are underlain with coal-bearing beds and that North Dakota contains 633,-

[1] U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 456. Also, Bulls. 285, 341, 381, 471, and 531.

329,800,000 tons of lignite. The coal is almost entirely in the Fort Union beds of the Eocene. The beds run as high as 30 feet in thickness and many of them are continuous for many miles. The Lance formation contains a little coal, but in most places the seams are too thin to work. The latter formation does not appear in the northern part of North Dakota but is extensively distributed around the border

FIG. 134. — Lignite seam, Williston, N. Dak. (After F. Wilder, photo. Reprinted by permission from Ries' Economic Geology, published by John Wiley & Sons, Inc.)

between the Dakotas. The lignite is mined only along the main lines of the railroads and chiefly for domestic purposes, steaming and producer gas.

Montana.[1] — This state contains extensive coal lands. The Fort Union Basin of the Dakotas extends into this state and contains over half as much lignite as North Dakota in nearly the same area. The other areas in Montana are the Bull Mountain field, the Assinniboine region, the Judith Basin region, the Flathead River field, the Mountain fields, the Yellowstone region and the Red Lodge-Bridger field. The Bull Mountain field, which is being developed, contains rocks of Fort Union and Laramie age or slightly older. The

[1] U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 460. Also, Bulls. 316, 341, 356 (Great Falls Field) 381, 531, 647 (Bull Mountain), University of Montana, Bull. 4, by Rowe.

structure of the synclinal basin is simple. The coal varies from lignite in the Tertiary rocks to subbituminous and low-grade bituminous in the older formations. There are 20 seams over 2 feet thick and the " Mammoth " seam runs from 8 to 15 feet.

The field which is most largely worked is the Red Lodge-Bridger field where coal has been mined for a good many years. There are seven seams running from 3 to 12 feet in thickness. The coal is high-grade subbituminous, fairly high in moisture, and it soon breaks down or " slacks " when exposed to the air.

The Great Falls field in Cascade County, forming part of the Judith Basin region, produces considerable coal at Sand Coulee, Stockett and Belt. The coal is bituminous and dirty and it occurs in the Kootenay series of the Lower Cretaceous. The seams in some places reach nearly 15 feet in thickness. The North Fork Flathead River field is considered to contain unimportant bituminous and subbituminous coals of Jurassic age as well as the Cretaceous coals. The Assinniboine region is represented by the Milk River Field. The strata belong chiefly to the Montana group and are buried under glacial drift. All the coal in this field occurs in the Judith River formation of the Montana series except a little lignite in the Fort Union. The coal beds are, as a rule, lenticular and they run up to 9 feet in thickness. Faults and folds are common in this region. The coal is of fairly good subbituminous grade. In many areas in this state, as in the other western states, the coal beds have been burned, leaving slag and reddened rock. This is partly due to the ease with which the coal ignites.

The Pacific Coast Province[1]

California.[2] — The coal fields of California are very limited and there is no prospect of her ever becoming a great coal-mining state. The fields are also widely scattered, the main ones being as follows: Ione Mine in Amador County, Mount Diablo of Contra Costa County, Coral Hollow of Alamada County, Priest Valley and Trafton of San Benito County, and Stone Canyon of Monterey County. The

[1] Smith, G. O., The coal fields of the Pacific Coast. U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 473, 1902.

[2] Campbell, M. R., Coal of Stone Canyon, Monterey County. U. S. Geol. Survey, Bull. 316, p. 435, 1907.

coal in Stone Canyon is of bituminous rank with a composition approaching cannel. A bed 10 to 14 feet thick has been exploited.

The coals in the southern part of the state are bituminous and non-coking; those in the northern part are lignite, and those lying between these fields are subbituminous. Practically the only coal produced in the state, in some years at least, is lignite, which comes chiefly from the Ione Mine, Amador County. The coal is of Eocene and Miocene age. The coal industry of all the western states where fuel oil is found in abundance is vitally affected by that commodity and will continue to be so affected as long as oil is abundant.

Oregon.[1] — Oregon has very little coal and comparatively little mining has been done. In the Coos Bay field, in the southern part of the state, mining has been carried on and coal is shipped from the Beaver Hill and Newport mines. The coal is subbituminous in grade. The coal in this field is difficult to mine and much of it lies below sea level. In the Eden Ridge field, also of Coos County, the coal is bituminous and coking as the strata have suffered more squeezing than in other parts of the county. The coal is shaly and dirty. A number of other small fields in the state contain thin or impure coal seams, but there is no development in these fields. The Oregon coals are used for domestic and steaming purposes.

Washington.[2] — There are five coal fields, confined to the western and central parts of this state. They are the North Puget Sound in Skagit and Whatcom counties, South Puget Sound in Pierce and King counties, Puget Sound basin lying just east of Seattle, the Roslyn field in Kittitas County on the east flank of the Cascade Mountains, and the Southwestern field in Lewis and Cowlitz counties.

Washington is the only state in the Pacific province containing coking coals. These coals are in the North and South Puget Sound fields. The coals of this state range from subbituminous rank to anthracite. Coal has been mined in Washington since about 1860, the first mined being lignite, but spontaneous combustion closed operations. The bituminous coals are used chiefly on the ocean-going ships and the subbituminous for domestic purposes.

[1] Diller, J. S., Coos Bay Coal Field. U. S. Geol. Survey, 19th Annual Rept., p. 309, 1899.

[2] Washington Geol. Survey, Vol. II and Bull. 3. Also U. S. Geol. Survey, Bulls. 531 and 541.

The coals in King County lie under a heavy mantle of glacial drift. They are of Eocene age, like the other coals of the state, but owing to the compression which they have suffered in mountain building they have been changed from lignite to subbituminous and bituminous rank. In this county the beds have been highly folded and broken so that in parts of the field mining is difficult. The ash in the coal is high. Pierce County carries the best coals in Washington so far as known, as coals are bituminous, semibituminous and even anthracite where the rocks have been highly squeezed, broken and intruded by igneous rocks. The bituminous coals will coke.

In the Roslyn field the beds lie regularly, and it is easy to mine the Roslyn seam, running between 2 and 3 feet thick. There is also another seam known as the "Big" seam which is full of partings and very dirty. It reaches nearly 20 feet in thickness. The coal is bituminous.

The Puget Sound field is characterized by the tremendous number of coal seams which the formations contain. In one place there are about 125 seams, the majority of which are unworkable. This indicates a great number of changes, probably rapid ones, in the climatic or topographic conditions, or both, during the formation of these beds.

Alaska[1]

The coal fields of Alaska are but partially known, as so little geological work has been done on this tremendous area. More or less work has been done on certain regions and fields, and a rough estimate of the character of the coals and their resources may be given. The accompanying map and the following table show the geographical and geological distribution of the coals, so far as known.

The following fields or areas are recognized: Bering River, Matanuska, Cook Inlet, Alaska Peninsula, Nenana, Northern Alaska and many other less-known fields and areas.

[1] Brooks, Alfred H., and Martin, George C., Coal resources of the world. International Geological Congress, Vol. II, 1913. U. S. Geol. Survey, 22nd Annual Rept., Pt. III, p. 515, 1902; and Bulls. 284 and 314.

STRATIGRAPHIC POSITION OF ALASKAN COALS*

System	Series	Character of coal	Principal distribution
Quaternary	Pleistocene	Lignitic	Yukon basin and other parts of Alaska.
Tertiary	Pliocene	Lignitic	Yakutat Bay and other localities.
	Miocene or Eocene	Anthracitic and bituminous.	Bering River.
	Eocene	Chiefly lignitic, also some bituminous and subbituminous	Throughout Alaska, notably on Cook Inlet, in Matanuska Valley and Yukon Basin.
Cretaceous	Upper Cretaceous	Subbituminous and bituminous	Alaska peninsula, Yukon and Colville basins.
Jurassic		Lignitic, subbituminous and bituminous	Near Cape Lisburne and in Matanuska Valley.
Carboniferous	Pennsylvanian	Subbituminous	Yukon River.
	Mississippian	Bituminous	Twenty miles south of Cape Lisburne.

* Table by A. H. Brooks and G. C. Martin, Coal Resources of the World.

The Bering River is an important field lying 25 miles northeast of Controller Bay. The coal beds run from 3 to 25 feet in thickness, in the Kustaka formation which is about 2000 feet thick and of Miocene age. The field is greatly folded and faulted and in many places, especially in the eastern and western ends of the field, the coal beds are so badly crushed as to ruin the coal. The coals vary from anthracite, averaging about 81 per cent, to semibituminous with 72 per cent fixed carbon. Some of the bituminous coal will coke.

Another important field is the Matanuska, lying along the valley of the Matanuska River, about 25 miles from Knik-Arm. The measures are deeply covered with gravel in parts of the field. The rocks are of Eocene age and in the eastern part of the field highly folded and faulted. It is probable that the field will cover about 100 square miles. The seams range from 3 to 32 feet in thickness. In the west end of the field the coal is lignite and in passing eastward it changes to bituminous coal and anthracite. Some of the coal is high in ash but the average content is favorable.

In the Cook Inlet field lignite occurs in the Kenai formation of

the Eocene. There are fifteen or more seams running from 3 to 7 feet in thickness. On the Alaska Peninsula lignite occurs in the Kenai formation, but better coal is found in the Chignik formation of the Upper Cretaceous around Chignik Bay and Herendeen Bay. In this formation the coal is subbituminous and bituminous of fair quality, but little is known of the extent of the seams.

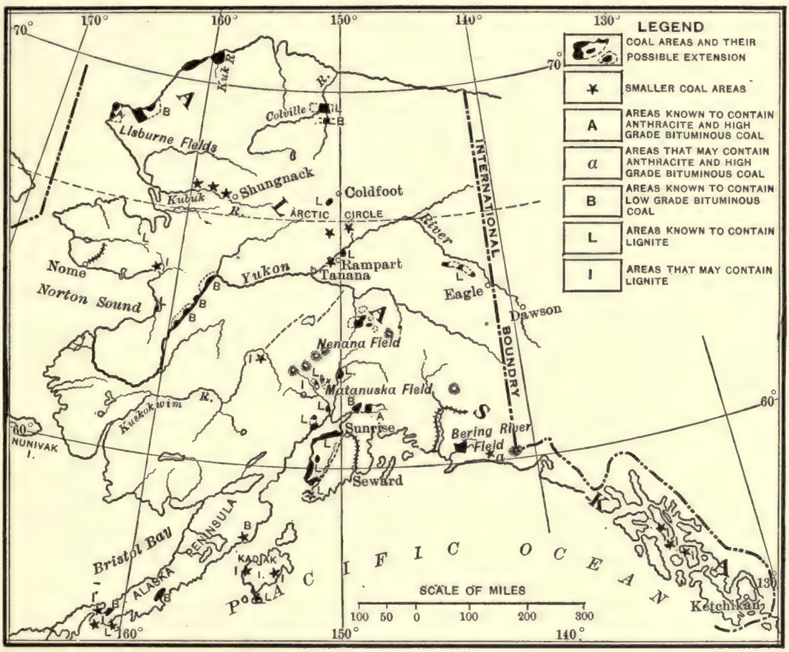


FIG. 135. — Alaska, showing distribution of coal deposits. (After A. H. Brooks. Reproduced from "Coal Resources of the World." Published by the 12th International Geological Congress, Toronto, Canada.)

In Northern Alaska there are three coal-bearing formations: one is Carboniferous, supposedly Mississippian, containing high-grade bituminous coals with low ash content; another is Jurassic with a large number of beds of subbituminous coal running as high as 12 feet in thickness; and the third is Tertiary, carrying lignite. The older beds are considerably folded and faulted but those in the Tertiary are quite flat.

In the Nenana field there are a number of beds running from 3 to 30 feet in thickness. They occur in the Eocene, and the coal is mostly lignite.

The table given below is a summary of the estimates of Brooks and Martin for the coal fields of Alaska, in so far as information is available.

ESTIMATE OF TONNAGE OF COAL IN ALASKA*

Regions	Area in square miles		Estimated amount of coal in metric tons (1 metric ton = 1.1023 short tons)					Total
	Known coal fields	Possible coal fields	Lignite	Sub-bituminous	Bituminous	Semibituminous	Anthracite and semianthracite	
Pacific Coast	458	8,585	1,971,000,000	485,000,000	2,000,000	1,293,000,000	1,931,000,000	5,682,000,000
Interior Region	440	4,493	9,731,000,000	53,000,000	14,000,000			9,798,000,000
Arctic Slope	312	3,059	910,000,000	3,143,000,000		60,000,000		4,113,000,000
Totals	1,210	16,137	12,612,000,000	3,681,000,000	16,000,000	1,353,000,000	1,931,000,000	19,593,000,000

* This estimate is based on seams 3 feet or more in thickness and lying less than 3000 feet deep for high-grade coal (anthracite to semibituminous), and less than 2000 feet deep for lower grades (bituminous to lignite).

Mexico

The coals of Mexico are but little developed. Only one state produces any quantity and submits regular reports of production. There are several regions, according to R. T. Hill[1], which contain coal, and the coals are of three geological ages: Tertiary, Upper Cretaceous and Triassic. The Tertiary lignites represent a continuation of the deposits of that age in the United States, but so far as known they are of no importance in Mexico. The Triassic coals occur in two districts, the Mixteca district in the south where there are a large number of seams of workable thickness but too high in ash to be valuable, and the Santa Clara field where the coal is semi-anthracite and anthracite because it has suffered much from compression and igneous intrusions. Natural coke and graphite in sufficient quantity to be mined have resulted from these disturbances. The seams run 4, 8 and 10 feet in thickness.

The producing fields are all Montana (Upper Cretaceous), in age and they occur in Coahuila. They are known as the Eagle Pass, Sabinas and Barroteran fields. There is a small production from

[1] Hill, Robert T., The coal fields of Mexico. Coal Resources of the World, Vol. II, p. 553.

the Eagle Pass field, which is situated in the vicinity of Eagle Pass, Texas and Porfirio Diaz in Mexico. This field is a continuation of the field of the same name in Texas. In the Sabinas field there are two beds 4 to 6 feet thick, of good, coking, bituminous coal. A clay seam between the beds causes some difficulty in working. The Barroteran field is a continuation of the Sabinas field along the north side of the Santa Rosa Mountains. In this field the seam is 8 feet thick with 14 inches of clay and shale and it is regular and persistent. The coal is bituminous and coking. A number of American companies are working mines in Mexico in the Sabinas and Barroteran fields and a considerable number of coke ovens are in operation.

Central America[1]

The only countries in Central America reporting any coal resources are Honduras and Panama. The former country reports 5,000,000 metric tons, all lignite except about 1,000,000 tons of bituminous coal in the district of El Paraiso. The beds run from 1 foot 6 inches to 4 feet in thickness, but they have never been mined. Panama has a little lignite in the province of Bocas del Toro on the coast and in the interior. That on the coast is largely submarine and under porous strata while that in the interior is too high in sulphur to be valuable. It is interesting to note that the sulphur is said to increase as the volcano Chiriqui is approached.

West Indies

Cuba has no coal and the only resources reported for the West Indies are found in Trinidad. The coal has not been exploited, but there are two districts in which it is known to occur. These are near Manzanilla and Sangre Grande on the east coast. In the former area the coal is lignite, the seams thin, not exceeding 4 feet, and the deposit is poor in quality. In the Cunapo district, near Sangre Grande prospects are a little better. There are two seams of subbituminous coal, one of which is 5 feet thick and can be traced for a considerable distance, but they lie on an irregular bottom and are probably not of much importance.

[1] Coal Resources of the World.

South America

South America is apparently deficient in good coal deposits, and very little definite information has been collected on her coal resources as the best available data place her actual reserve at 2,089,000,000 metric tons and her probable reserve at 32,010,000,000 tons. The geological ages of the coals are Permo-Carboniferous, Cretaceous and Tertiary, (Plate XV). The following countries are reported to carry at least some coal: Colombia, Venezuela, Ecuador, Peru, Bolivia, Argentina, Brazil and Chile. The coals vary from anthracite to lignite in character.

Colombia.[1] — Coal is found in several departments of the country, but worked in few. Mines are operated in the vicinity of Bogota in the Departments of Cundinamarca and in Boyaca and to a lesser extent in the Department of Antioquia. The coal is bituminous and most of it is used locally for railroads, and for domestic and metallurgical purposes. According to Gamba the largest fields are in the districts of Cauca and Valle where there are three seams of medium-grade bituminous coal, with an aggregate thickness of 6 feet 6 inches and estimated resources of 20,000,000,000 metric tons in seams over 1 foot thick and less than 3000 feet deep. Little or no mining has yet been done in these departments. The Departments of Cundinamarca and Boyaca have the same number of seams with the same aggregate thickness of coal and resources of 6,000,000,000 metric tons. The same number of seams with the same aggregate thickness contain 1,000,000,000 metric tons in Antioquia. No estimate of the resources of the Department of Narino is available, but they are believed to be very large as there is supposed to be a large unstudied field in the vicinity of the Putumayo River. These figures make a total estimate of twenty-seven billion tons in the best-known fields. Miller and Singewald[2] quote Ospma as saying that in the western coal area there are as many as six seams, one as much as $9\frac{3}{4}$ feet thick. Most of the coal is a hard compact lignite except where it has been subject to considerable metamorphism. Apparently this coal is a subbituminous coal, as the term is used in the United States.

[1] Gamba, F. P., Coal resources of Colombia. Coal Resources of the World, 1913.

[2] Miller, B. L., and Singewald, J. T. Jr., Mineral deposits of South America. p. 357, 1919.

PLATE XV. — Coal fields of South America. (Reproduced from "Coal Resources of the World," published by the 12th International Geological Congress, Toronto, Canada).

F. Lynwood Garrison[1] mentions some peculiar coal from Cacagual on the Taraza River. There are several seams varying from a few inches to 5 feet. The coal is compact and glassy and it resembles cannel. It possesses a distinctly laminated structure and it can be lighted with a match. It burns with a glow like punk and not with a long flame as cannel does. This coal has the peculiarity of being overlain by rich gold-bearing gravels. Analyses show its composition to be as follows: Moisture, 13.6 to 15.36; Volatile matter, 38.10 to 47.41; Fixed carbon, 44.40 to 32.67; Ash, 3.80 to 4.56 and Sulphur, 0.54 per cent. Garrison also quotes analyses by Percy which show coals from Colombia with oxygen and nitrogen combined varying from 12.06 to 22.12 per cent.

The better coals of Colombia are of Upper Cretaceous age. There is considerable lignite of Tertiary age, but little is known regarding it.

Venezuela. — According to Miller and Singewald[2] coal is widely distributed in Venezuela north of the Apure and Orinoco rivers and the Llanos. The age is doubtful, probably Cretaceous and Tertiary. All the coals are lignites or subbituminous except for one area of semianthracite. There are numerous seams, the thickest reported running up to about 10 feet. Some of the areas in the Balcelonia district have been highly folded.

Ecuador, Peru, Bolivia. — Ecuador does not report any operating coal mines but this country has a little coal of good quality, varying from lignite to anthracite. The places so far mentioned are at Cojitambo, Mangan and Biblian in the province of Cañar. Anthracite occurs at San Antonio de Pomasqui, north of Quito. It is of Tertiary age.

Peru has rather extensive coal-bearing areas running through the Andes Mountains. The quality of the coal varies from low-grade bituminous to anthracite. Her resources have been placed at approximately two billion tons, of which seven hundred million are anthracite and semianthracite. The age of the coal is Cretaceous or Tertiary. According to Borlkjof[3], anthracite containing from 84 to 87 per cent fixed carbon, occurs in Cajabamba province, and in

[1] Garrison, F. Lynwood, Mining and Scientific Press. Vol. 98, p. 219, 1909.

[2] Op. cit., p. 542.

[3] Borlkjof, J. Camilo B, The coal deposits of Peru. Eng. and Min. Jour., Vol. 88, p. 983, 1919.

Chota, about 140 miles from the Pacific, there are four anthracite beds from 13 to 65 feet thick. There is estimated to be 700,000,000 tons of coal in this area. There is a large amount of coal in the Department of Lima and in the Province of Chamcay, at Checras. In the provinces of Parquin and Quiruragra there is a bed which reaches a thickness of 13 feet and the resources are estimated at 720,000,000 tons. This is the largest and most important field in Peru. It is situated near the Cerro de Pasco copper camp and coal is being mined by this company. A number of coal mines are worked in Peru, some of them being highly gaseous. It seems probable that Peru will be found to contain much larger reserves than those mentioned above and that she will be quite an important producer of high-grade coal in the future.

Practically nothing is known regarding the coal deposits in Bolivia beyond the fact that they seem to be of small importance and to be Permo-Carboniferous in age. A few outcrops of impure seams occur on Lake Titicaca but little work has been done on them. The inhabitants of that country, most of which lies at an elevation of over 8000 feet above sea level, suffer a great deal from cold owing to the great altitude and the scarcity of fuel.

Brazil. — A number of coal mines have been operated from time to time in Brazil, but so far very little coal sufficiently free from slate and low enough in sulphur and ash to make a good industry has been found. The extensive report of I. C. White[1] shows that only by laborious picking, washing and briquetting can a satisfactory fuel be obtained. The most favorable localities are in the south near the Uruguay border. The coal occurs in the Rio Bonita beds of the lower Permian which are correlated with the lower Karroo of South Africa.

Argentine Republic. — No coal deposits of importance have been found in this great country. Thin seams are found in a number of places, as the Permo-Carboniferous rocks outcrop along the eastern border of the Andes and a seam has in recent years been exploited at Salagasta in the province of Mendoza. It is reported that a seam 10 to 12 feet thick was struck at a depth of about 2000 feet. The coal is fairly low-grade bituminous. In Mendoza there are

[1] Final Report of I. C. White, Chief of the Brazilian Coal Commission, Rio Janiero, 1908.

some beds of Albertite which somewhat resembles coal but is a solid derived from petroleum.

Chile.[1] — There are two provinces in Chile which contain coal fields of importance and in which coal is being worked. These are Arauco and Concepcion. In the former the places where mines are worked are Maquehua, Arauco, Pilpilco Cuyinco, and Lebu and in the latter Penco, Lirquen, Coronel and Lota. The seams worked vary in thickness from 0.70 meter to 1.85 meters. At Coronel eight seams are mined and at Arauco six seams. In the Penco district the coal is mined to a considerable extent beneath the sea. The strata are little folded as a rule but normal faults are fairly numerous. The age of most of the Chilian coal is Tertiary, probably Oligocene or Miocene, and it is of bituminous rank; much of it being of inferior quality. The coal resources of Chile are estimated at 2,082,000,000 metric tons.

[1] Michado, Miguel R., Le Charbon du Chili et sa Distribution Geographique. Coal Resources of the World, Vol. II, p. 581.

PLATE XXI. — The Coal fields of western Europe. (Reproduced from

PLATE XVI. — The Coal fields of western Europe. (Reproduced from "Coa
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sources of the World." Published by the 12th International Geological Congress, anada).

CHAPTER XIV

THE COAL FIELDS OF THE WORLD — EUROPE AND ASIA

Europe[1]

Europe was the mother of the coal-mining industry, which still flourishes on that continent, although in some respects America has surpassed her in the development of mining operations. Although her resources are small compared with those of America, Europe is well supplied with high-grade coal and she is more careful to utilize a greater proportion of it than we have been in America.

The table given below shows the actual and estimated resources of coal in the various countries of the continent and the accompanying maps picture the area and distribution of the coal fields (Plates XVI and XVII.)

This table indicates that the German Empire controls by far the largest coal resources of the countries of Europe. Great Britain comes second, Russia in Europe third, Austria fourth and France fifth. Italy has almost no coal in comparison with her population. Russia has a large estimated tonnage of anthracite — almost twice that of the United States and second only to China. The figures given for Roumania do not properly indicate her probable reserves. The annual production of European countries is given on page 335.

Great Britain.[2] — Great Britain has long been one of the leading coal-producing states of the world and she is surpassed in production

[1] For comprehensive descriptions of the coal deposits of Europe see Atlas général des Houillères (Text and Atlas) by E. Gruner et G. Bousquet, Comité Central des Houillères de France, Paris, 1911. Also Coal Resources of the World, International Geological Congress. Vol. I.

[2] For comprehensive reports see the Coal Resources of Great Britain by A. Strahan, Coal Resources of the World. Also various Memoirs of the Geological Survey of England and Wales on individual fields. Analyses of British Coals and Coke and the Characteristics of the Chief Coal Seams worked in the British Isles, by Greenwell and Elsden. Colliery Guardian, London, 1907. Reports of the Royal Commission on Coal Supplies, 1905.

* COAL RESOURCES OF EUROPE IN MILLIONS OF METRIC TONS
(1 metric ton = 1.1023 short tons)

	Actual Reserve			Probable Reserve			Total
	Class of Coal			Class of Coal			
	A	B and C	D	A	B and C	D	
	Anthracite including some dry coals	Bituminous coals	Subbituminous coals, brown coals and lignites				
Great Britain and Ireland:							
England		B 79,869			B 46,030		
Wales	8,672	B 31,402		13	B 195		
Scotland	2,500	B 18,876			B 1,685		
Ireland	172	B 8			B 111		
	11,344	130,155		13	48,021		189,533
Portugal	20						20
Spain:							
Asturias	1,008	B 2,016 C 2,016		148	B 296 C 296		
Other fields	42	B 358 C 386	394	437	B 567 C 431	373	
	1,050	4,776	394	585	1,590	373	8,768
France:							
North of Ardennes Massif	520	B 2,600 C 670		1,690	B 6,260 C 420		
Eastern		B 3			B 13 C 630		
Armorican Massif		B 2		7	B 24		
Central Massif	59	B 233 C 114		890	B 1,079 C 632		
Alps	2			103			
Lignite areas			301			1,331	
	581	3,622	301	2,690	9,058	1,331	17,583
Italy	1		51	143		48	243
Greece			10			30	40
Bulgaria					C 30	358	388
Denmark (Faroes)						50	50
Netherlands	50	159		270	3,923		4,402
Belgium							
Campine:							
Limburg					B 7,000		
D'Anveres					B 1,000		
Namur					B 3,000		
					11,000		11,000

COAL RESOURCES OF EUROPE (*Continued*)

	Actual Reserve			Probable Reserve			Total
	Class of Coal			Class of Coal			
	A	B and C	D	A	B and C	D	
*	Anthracite including some dry coals	Bituminous coals	Subbituminous coals, brown coals and lignite				
Germany:							
Saar district		16,548					
Westphalia		56,344			157,222		
L. Silesia		B 718			B 2,226		
U. Silesia		B 10,325			B 155,662		
Saxony		B 225	3,000				
Left of the Rhine		B 10,458					
Other districts		B 247					
North German States			6,069			3,676	
Bavaria			75			293	
Hesse			169			99	
		94,865	9,313		315,110	4,068	423,356
Hungary		B 4	354		B 109	1,250	1,717
Austria		B 2,970	12,231		B 38,012	663	53,876
Bosnia and Herzegovina			1,700			1,976	3,676
Servia		B 2	58		B 43	426	529
Roumania			3			36	39
Sweden		B 106			B 8		114
Russia:							
Dombrova, (Poland)					B 2,525		
Moscow						1,578	
Donetz				37,599	B 18,014		
S. W. Russia						43	
W. Urals		B 57					
Caucasus			12		B 253	25	
		B 57	12	37,599	20,792	1,646	60,106
Spitzbergen					8,750		8,750
Total for Europe	13,046	236,716	24,427	41,300	456,446	12,255	784,190

* From the Coal Resources of the World. Estimate based on seams more than 1 foot thick and less than 4000 feet deep and on seams more than 2 feet thick and between 4000 and 6000 feet in depth. For detailed description of the classes of coal, see Classification of Coals, Chapter V.

TABLE SHOWING THE GEOLOGICAL AGES OF EUROPEAN COALS

	England and Wales	Scotland	Ireland	Portugal	Spain	France	Switzerland	Italy	Greece	Turkey	Bulgaria	Denmark	Netherlands	Belgium	Germany	Hungary	Austria	Bosnia-Herzegovina	Serbia	Roumania	Sweden	Norway	Spitzbergen	Russia in Europe
Pleistocene							l								l									
Pliocene								L							l	L		L		L				l
Miocene								l							L **B**	L	L	L		L			**B**	L
Oligocene								l							L **B**	L	L	L						
Eocene							l a								L	L								
Tertiary undifferentiated					L	l			L	L	**B** L	l			L				L					L
Upper Cretaceous					L	L					B				l	L	b	l	L					L
Lower Cretaceous																								
Jurassic				b		l	a					l				L B	b		b	b	b		b	l B b
Triassic (Rhaetic)						l		b				l					b	b			b	c		
Permian															b		b	b						
Upper Carboniferous (Pennsylvanian)	A S B	A S B	a B	a	B	B A	a	a	B?	a B	a		B A S	B	B	B	B	b	b	a b			b	A B
Sub-carboniferous (Mississippian)		A S B	B			B A				B					B									A Bc
Upper Devonian																						b		

A, Anthracite and semianthracite; S, Semibituminous; B, Bituminous; **B**, Subbituminous; L, Lignite. Capital letters indicate important deposits and lower case relatively unimportant deposits of the same type.

only by the United States. She has given us many of our mining methods and many of the principles involved in our mining apparatus as well as a wonderfully efficient and hardy class of mining men. Her coal supplies have been one of the very important factors in the attainment of her high position in the industrial and commercial world, and she has exported coal lavishly to those countries less favored by nature in coal deposits than she. The tables given above show that she is exhausting her supplies at a much greater rate in proportion to her resources than any of the other great commercial countries with the exception of France. The conclusion of the Royal Commission on Coal Supplies in 1871[1] was that there was enough coal in sight to continue the existing rate of production for 1273 years, but that, considering the probable rate of increase in production, there was sufficient coal to last between 325 and 433 years. The latter figure would be much too high if the rate of increase should continue a few years longer.

Several very thorough reports have been prepared on the coal resources of the islands and the available supplies are very well known. The fields are usually divided into two groups, known as (*a*) the Visible and Proved fields; and (*b*) The Concealed and as yet unworked fields. The first group includes those fields where the Coal Measures are not deeply buried by later formations, and the second group those fields where they are deeply covered but where they are known to exist in synclinal basins. In computing the resources it was assumed that a thickness of 1 foot of coal represents 960,000 tons per square mile, or 1500 statute tons per acre. The various fields with the number and thicknesses of the seams, the character of the coal and the resources of each field are set forth in the following table compiled by Strahan.

[1] Reports of the Royal Commission on Coal Supplies, 1871 and 1905.

COAL RESOURCES OF ENGLAND AND WALES

(Including seams of 1 foot and over to a depth of 4000 feet.)

District	Coal Seams			Actual Reserve (Calculation based on actual thickness and extent)		Probable Reserve Approximate Estimate			Possible Reserve
	No	Thickness	Area sq. miles	[1]Class of Coal	Metric tons (1 metric ton = 1.1023 short tons)	Area sq. miles	Class of Coal	Metric tons	
(Visible fields)									
Monmouthshire	12–20	1 to 6½ Agg. 47	96	B_1, B_2, B_3	3,387,042,013				
Glamorgan, Brecknock, Carmarthen	40	1 to 11½, Agg. 85-120	693	A_1, A_2, B_1, B_2	32,314,404,073	20	B_1, B_2, B_3	195,500,000	
Pembrokeshire	8-18	1 to 6½, Agg. 21–33	33	A_1	308,603,353	2	A_1	13,000,000	
Forest of Dean	15	1 to 4¾	28	B_1 B_2, B_3	199,760,267				
Bristol and Somerset	40	1 to 6, Agg. 90	238½	B_1, B_2	4,266,200,773				
North Staffordshire	30–36	1 to 10, Agg. 148	110	B_2, B_3					
Cheadle	17	1 to 6, Agg. 65½	18	B_2, B_3	7,256,299,150				
South Staffordshire	6–11	1 to 30, Agg. 65	149	B_2, B_3					
Warwickshire	10	1 to 16, Agg. 40	56	B_2, B_3	1,445,296,102				
Leicestershire	22–33	1 to 16, Agg. 94	84	B_2, B_3	2,494,374,878				
Shropshire and Worcestershire	7	Agg. 15	98	B_2, B_3	364,927,899				
Lancashire and Cheshire	23–31	1 to 9, Agg. 46–95	554	B_2, B_3	5,636,427,289				
Flintshire including Neston	14	1 to 12 Agg. 58	87¾	B_2, B_3	1,080,628,538				
Denbighshire	17	1 to 12, Agg. 37–65	91	B_2, B_3	1,455,086,080				
Anglesey	7	Agg. 6	5	B_2, B_3	29,000,000				
Yorkshire, Derbyshire and Nottinghamshire	15–21	1 to 9½, Agg. 40–52	1376	B_1, B_2, B_3	40,254,216,885	760	B_1, B_2, B_3	14,853,600,000	
Northumberland and Durham	26	1 to 6, Agg. 77	849	B_1, B_2, B_3	11,023,394,416				
Cumberland and Westmoreland	10–20	1 to 11, Agg. 28–57	253	B_1, B_2, B_3	2,186,301,213	Indefinite		1,211,800,367	2,518,000,000
Ingleton	8	1 to 9, Agg. 23½	16	B_1, B_2, B_3	33,600,000				
(Concealed fields)									
Kent						206 (Supposed)		2,000,000,000	
Oxfordshire and Gloucestershire									
North Staffordshire						Unknown			
South Staffordshire (Westwards)						96	B_2, B_3	2,955,000,000	
South Staffordshire (Eastwards)						220 292	B_2, B_3 B_2, B_3	8,601,600,000	
Cheshire Basin						Indefinite	B_2, B_3	153,500,000	9,990,000,000
Chester, Wirral and Liverpool						200	B_2, B_3		2,932,000,000
Vale of Eden and Solway Firth						40	B_2, B_3		814,500,000
Totals					113,735,562,929			29,984,000,367	16,254,500,000

[1] For description of classes of coal see under Classification of Coals, Chapter V.

In addition to the totals given above there are calculated to be 6,207,847,000 metric tons of actual reserve in seams running over 2 feet in thickness and lying at depths between 4000 and 6000 feet.

THE COAL RESOURCES OF SCOTLAND
(Including seams of 1 foot or over to a depth of 4000 feet.)

District	Coal Seams			Actual Reserve (Calculations based on actual thickness and extent)	
	No.	Thickness (Aggregate)	Area, sq. miles	[1]Class of Coal	Metric tons (Metric ton = 1.1023 short tons)
Clackmannan and Perth	17	20 to 50 feet	41	B_2, B_3	916,243,044
Fife and Kinross	38	100 to 140 "	148	B_2,B_3	5,263,432,444
Under the Firth of Forth	40	75	130	B_1, B_2, B_3	4.252,000,000
Linlithgow	6	13½	61	B_2, B_3	683,663,883
Edinburgh, Haddington and Peebles	37	105	128½	B_2, B_3	3,143,148,115
Stirlingshire	25	59	135	A_1, A_2, B_1, B_2, B_3	1,600,629,550
Dumbartonshire	Few	Small	58	B_2	324,187,635
Lanarkshire	13	43	275	A_1, A_2, B_1, B_2, B_3	3,051,734,030
Renfrewshire	7	16½	73	B_2	134,965,370
Ayrshire	27	80	330	A_2, B_1, B_2	1,337,992,870
Dumfriesshire	8	40	26½	B_2	
Argyllshire (Kintyre)	8	45	2	B_1, B_2	
Argyllshire (Marvern)		Unknown possible reserve			
Sutherlandshire	2	5	3	B_3	1,000,000
					21,376,493,625

[1] For description of classes of coal see under Classification of Coals, Chapter V.

In addition to the actual tonnage reserve for Scotland mentioned in the above table there are probable reserves of 1,685,000,000 metric tons in seams over 2 feet thick lying between 4000 and 6000 feet in depth in the Firth of Forth, and in the Fife and Kinross districts.

The coals of Great Britain are all of the higher ranks, bituminous, semibituminous and anthracite. In England and Wales they all occur in the Coal Measures proper, or the Pennsylvanian as the term is used in the United States. In Scotland the Lower Carboniferous (Mississippian) carries good coal and there are thin workable seams in the Calciferous sandstone. The latter is a formation in the lower part of the Lower Carboniferous and should not be confused with part of the Devonian of America.

In England and Wales the Millstone grit is well developed and in some places it is very thick, reaching about 5500 feet in thickness in Lancashire. As in America it consists of quartz conglomerate and micaceous, arkosic sandstone. It carries small seams of coal. In Scotland it is in most places comparatively thin and it is a sandstone known as "Moor rock." This rock also carries thin coal seams.

The Coal Measures reach a maximum thickness of between 10,000 and 12,000 feet in Wales and in the midst of the series there is a sandstone and conglomerate known as the Pennant grit. It is in many places almost barren of coal but in others there are a number of good seams. In a few localities it carries pebbles of coal showing that vegetal matter had already formed coal which could be eroded when this formation was laid down. In many of the coal fields, fire clay or "seat earth" is found beneath the coal seams, leading early writers to consider that this was always an accompaniment of coal seams. Iron ore, in form of the carbonate, often known as "black band," occurs in a number of the fields. This ore owes its origin to the presence of abundant carbon dioxide derived from decaying vegetation in the waters when the iron was laid down.

Cannel coal is abundant in some fields, and some of it carries numerous fish remains showing that the spores which formed the coal were laid down in ponds of open water where fish could live. A peculiar coal known as Torbanite, which is a boghead, has long been mined at Torbane Hill, Scotland. It is similar to an oil shale in the products derived from distillation but it is nevertheless a type of coal. Its status was once fixed by law in an important suit.

Some fields are greatly faulted as, for example, the Cumberland field, and others are extensively intruded by basalt and other igneous rocks, especially some of the Scottish fields and the Coalbrookdale and Dudley fields of England. Mining has been carried on in England to a great depth, in some places exceeding 3000 feet.

South Wales.[1] — This famous coal-field occurs in parts of Monmouth, Glamorgan, Brecknock and Carmarthen counties. It occupies a syncline with steeply dipping strata on the southern limb.

[1] Strahan, A., and Pollard, W., Coals of South Wales with special reference to the origin and distribution of anthracite. Memoir Geol. Survey, England and Wales, 1915.

The Coal Measures, which reach a thickness of nearly 12,000 feet, may be divided into three divisions: a lower consisting mainly of shales and containing the bulk of the coal seams; a middle series known as the Pennant series consistly chiefly of sandstone and coal-bearing only in the western part of the field; and an upper series consisting mainly of shales carrying coal seams. The anthracite occurs near the northwestern and western part of the field and the same seams occur as bituminous coal in the southern and eastern portions of the field with the well-known semibituminous, smokeless steam coals lying between the two extremes, (Fig. 33). In one part of the field the anthracite reaches an undetermined depth. There is one condition which remains almost constant throughout the field and that is the higher fixed carbon of the coal in the deeper seams. In any section there is in almost every case a nearly uniform increase in the *fuel ratio* with depth. This has not, however, been responsible for the origin of the anthracite. Strahan and Pollard concluded that they could find no satisfactory explanation for the occurrence of the anthracite in one part of the field, semibituminous in another part and bituminous in another, as there are no igneous intrusions, there is no particular difference in the character of the vegetation forming the coal in different parts of the field, and the depth of burial or the length of time since burial will not account for the changes. They also doubt that pressure could cause the difference, but the writer believes that this is the only satisfactory explanation. The relative proportions of the various varieties of coal have been placed as bituminous 30.42 per cent; semibituminous, or steam coal, 47.31 per cent; anthracite 22.27 per cent.

In Glamorganshire the number of seams varies from twelve at the eastern end with an aggregate of 42 feet of coal to about forty in the western part with 120 feet of coal. In Pembrokeshire the Pennant series is found throughout the field. The number of seams in the eastern part runs from eight with 21 feet of coal to eighteen with an aggregate of 33 feet in the western part. The strata are highly disturbed and the coal is all anthracite.

It is believed that there is a large deposit of coal under Swansea and Carmarthen bays. A large fault with a throw of approximately 3000 feet runs under Swansea Bay and cuts the coal field so as to duplicate the measures.

Ireland.[1] — There are several coal fields in Ireland, the largest being the Leinster field covering 95 square miles in Kilkenney, Carlow and Queen counties. The coals occur in the Coal Measures and the seams which are worked are quite thin, varying from 1 foot 8 inches, to 4 feet. The Ballycastle field, 4½ square miles in area, in County Antrim, contains seams 4 to 6 feet thick in the Lower Carboniferous. Numerous intrusions of dolerite cut this field. The Tyrone field carries a number of seams in the Coal Measures running up to 9 feet in thickness and the Gortnaskea seam is 6 feet thick with 22 inches of cannel. Other fields are the Lough, Allen and the Tipperary, besides other very small and scattered areas. In very few places in Ireland have the Coal Measures been covered by later rocks, and tremendous areas of these rocks have been eroded from the island.

France.[2] — France is deficient in coal for her future need as a great manufacturing country, and during the Great War she was cut off almost entirely from her best coal fields, which lie in the northeast. The coal areas have been divided into five regions by M. Defline as follows: (1) North of Ardennes Massif; (2) Eastern area; (3) In Armorican Massif; (4) In Central Massif; (5) In Alps, Maures, Pyrenees and Corsica.

The most important area is that of Valenciennes where the quality of the coal varies from anthracite to high volatile bituminous. The beds occur in the Westphalian series of the Coal Measures. There are a large number of seams, in the north basin as many as 69, but none are very thick, 2 meters being near the maximum. Parts of the Coal Measures have been faulted beneath the Silurian and Devonian formations and in the Pas-de-Calais basin the strata are extensively faulted and folded, (Fig. 73). A considerable amount of coal lies more than 4000 feet from the surface. The Boulonnais basin which is a continuation of that of Valenciennes is concealed by Cretaceous and Jurassic strata and the coal has been reached by borings. This basin is very small.

[1] Cole, B. A. J., and Lyburn, E. St. John, The coal resources of Ireland. Coal Resources of the World, Vol. II, p. 629.

[2] Defline, M., Les ressources de la France en combustibles minéraux. Coal Resources of the World, Vol. II, p. 649. Reports on individual coal fields in the publications of the Department of Public Works, Paris under the head of Études des Gîtes Minéraux de la France.

The basins in the east include Pont-a-Mousson and Ronchamp. The former is a prolongation of the Saarbruck basin and the Coal Measures are completely concealed beneath Triassic and Permian rocks at a depth between 2000 and 3000 feet. The measures belong to the Stephanian and Wesphalian series and, judging from borings, there are from one to seven seams with a maximum aggregate of about 20 feet of coal, although the coal-bearing strata have not been penetrated. Ronchamp field is in the small basin overlain by Permian strata. The Coal Measures belong to the Stephanian. There are 3 to 6 meters of bituminous coal in three seams.

Fig. 136. — Coal mine near St. Étienne, France. (Photo by E. S. Moore.)

The basins in the Armorican Massif include the Cotentin, Maine, Basse-Loire and Vendée. In the first field the coals are Stephanian and are of little importance since they are thin and of poor quality. The Maine field, in Brittany, contains coals of Dinantian or Lower Carboniferous age. The coal is an impure anthracite and occurs in very irregular seams, one reaching 60 meters in thickness at one point. The Basse-Loire field is also of Dinantian age and the rocks are highly folded and faulted. The coal is of poor quality. The Vendée field is of Westphalian age and the coal beds overlie gneiss and schist.

In the Central Massif there are a great number of small areas

of which the St. Étienne basin, near the town of that name, is the most important. The Coal Measures rest on granite and gneiss and belong to the Stephanian series. The coal contains from 7 to 35 per cent volatile matter. There is one seam known as the Grande Couche which reaches a thickness of 15 meters in this field and 20 meters in the Commentry basin. The number of seams runs as high as thirty-five in the St. Étienne basin.

The other fields in this region are all small, and the rocks are of Stephanian age. The Commentry basin is one of the most interesting. It is 9 by 3 kilometers in diameter, and is characterized by the large size of the boulders in the conglomerates in the Coal Measures. Some writers have suggested that these may be of glacial origin and others that they may be due to torrential streams carrying the material into a lake. It was in this basin that Fayol found the trees with tops headed downwards, which he regarded as evidence of drift origin. Some of the conglomerate in the Coal Measures carries pebbles of coal apparently derived from previously existing coal seams.

In the Alps seams of highly folded and for the most part inferior anthracite outcrop at various points from Briançon to the Little St. Bernard and run over into Italy and Switzerland. The seams are irregular in extent and thickness and reach a maximum thickness of about 10 meters.

Lignite occurs in an important basin known as the Fuveau basin, also in less important areas in the Vosges Mountains and in the Rhone basin. The Fuveau deposits are of Upper Cretaceous age and the seams run up to 2 meters in thickness. The lignite in the Vosges Mountains is Triassic and Jurassic in age and that in the Rhone basin is Upper Cretaceous and Tertiary.

Spain and Portugal.[1] — The most important coal-bearing provinces of Spain are Asturias and Leon in the northwest and Teruel in the east. In age the coals are Upper Carboniferous, Cretaceous and Tertiary, and they vary from anthracite to lignite. In Asturias there are as many as eighty seams with 112 feet of coal, but as a rule the seams are not numerous and none of them are very thick. The older coals are anthracite to bituminous and the Cretaceous and Tertiary coals lignite or subbituminous.

[1] Coal Resources of the World.

Portugal has little coal. Near S. Pedro de Cova there is a folded area of Coal Measures carrying anthracite, and near Tigueira the upper Jurassic strata contain bituminous coal of medium quality.

Switzerland.[1] — This is an old mining state in which coal has been mined for over two and a half centuries. The reserves for the future are not over 80,000 metric tons. The coal is Carboniferous, Jurassic, Eocene and Pleistocene in age and on account of the excessive folding and compression which the rocks have suffered most of it has been changed to anthracite and some of it even to graphite.

FIG. 137. — Highly faulted and squeezed coal seam in the mountains of Switzerland.

There is a little lignite of Eocene and Pleistocene age. The reserves of Switzerland in metric tons are placed at 4000 tons actual and 50,000 tons probable reserve in anthracite, and 500 tons actual and 25,000 tons probable reserve in brown coal, or a total of 79,500 metric tons. Much of this coal is difficult to mine owing to disturbances which the rocks have suffered.

Italy.[2] — Italy has but little coal and all but about 1 per cent of the coal produced is lignite or subbituminous in rank. Anthracite of Carboniferous age occurs in many places in highly folded rocks but most of it is of little economic importance. Most of the lignite and subbituminous coal mined comes from Tuscany and Umbria but these coals are widely distributed throughout the country. Beds up to 30 meters in thickness are reported as occurring in Tuscany. The age of the coal is Carboniferous, Triassic, Eocene, Miocene and Pliocene.

[1] Coal Resources of the World.
[2] Coal Resources of the World.

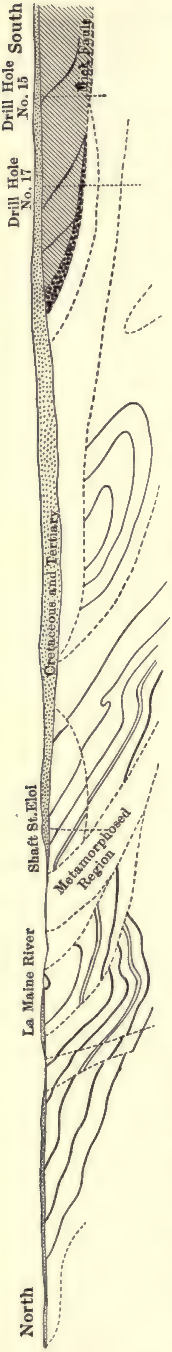

FIG. 138. — Section through the highly disturbed central portion of the Haine-Sambre-Meuse basin of Belgium. (After Armand Renier.)

Belgium.[1] — This country is comparatively well supplied with high-grade coal. The seams all occur in the Coal Measures which are divided into the Upper or Stephanian and the Lower or Namurian series, the former carrying the bulk of the coal in the Flenu and Charleroi formations. There are three fields in Belgium: (*a*) Dinant field in the southern part of the country and including numerous isolated small basins within a large syncline; (*b*) Namur field in the central part of the Haine-Sambre-Meuse trough; and (*c*) Campine field in the north. The Dinant field is unimportant. The Campine field contains the largest estimated reserves, they being placed at 8,000,000,000 metric tons. This field has not yet been worked as the coal lies deep and our knowledge is confined chiefly to borings. The Namur field is estimated to contain 3,000,000,000 metric tons reserve, and while there are numerous seams they seldom exceed 2 meters in thickness. The structure of the basin is complex, (Fig. 138). In 1910 the average thickness of the seams worked was 0.65 meters. The coal is chiefly bituminous with some cannel. Part of this basin is very deep and the deepest coal mines in the world, about 3900 feet, are found here. About one half of the coals of Belgium are coking.

Netherlands. — The Coal Measures in the Netherlands, which only outcrop in the south and east, are of the same age as those of Belgium and those of Westphalia between which they form a connecting link. The strata occur as great fault blocks. There are five possible fields of

[1] Renier, Armand, Les ressources houillères de la Belgique. Coal Resources of the World. Vol. III, p. 801. Also, Stanier, X., Des rapports entre la composition des charbons et leurs conditions de gisement. Annales Mines Belgique, V. 1900; and Denoël, L., carte et tableau synoptique des sondages du bassin houiller de la Campine. Annales Mines Belgique, IX, 1904.

which two are comparatively well known: (1) South Limburg with a maximum aggregate of 38 meters of coal of anthracite and bituminous rank; (2) South Peel of which little is definitely known but which is likely to be a comparatively large field. The other fields are known only by a few test borings. The coals are anthracite, semibituminous and bituminous with a good deal of gas coal.

Denmark. — Denmark has no coal production although before 1880 lignite was mined on Bornholm Island from Jura-Trias formations. There are nearly fifty seams but all are thin. On the Faroes Islands and in Iceland coal of Tertiary age, which has been changed locally from lignite to anthracite by basaltic flows and intrusions, is mined for local use.

Germany.[1] — Germany contains the largest supplies of coal of any of the European countries so far as known. The coals are of Carboniferous, Permian, Cretaceous, Tertiary and Pleistocene ages. The Tertiary and Pleistocene coal is lignite, or Braunkohle, and the Carboniferous is bituminous coal, or Steinkohle. There are six districts containing Carboniferous strata, as follows: (1) Saar; (2) Westphalia and Rhine province; (3) Lower Silesia; (4) Upper Silesia; (5) Saxony; and (6) Left of the Rhine. Saxony contains some Permian beds. There are considerable areas of Cretaceous coals which are but little known and there are four districts containing lignite. The latter are: (1) Prussia and the North German States; (2) Saxony with Oligocene and Miocene beds; (3) Bavaria; and (4) Hesse, the latter two containing coals in undifferentiated Tertiary formations.

The Saar district includes parts of Alsace-Lorraine, Prussia and the Palatinate in which a large area of the Coal Measures (Ottweiler and Saarbruck formations) together with Permian and Mesozoic formations have been folded into a large anticline. Erosion has removed the upper beds so that the Coal Measures are well exposed except in the southwest portion where they are deeply buried and much water in porous strata causes trouble in mining. The total thickness of coal worked amounts to over 40 meters and the formations are divided in vertical section according to the types of coals which they contain, as follows: The *fat coal*, the *lower flaming coal group*, the *upper flaming coal group*, and the *dry coal group*. The

[1] Die Kohlenvorrate des Deutschen Reiches. Coal Resources of the World. Vol. III, p. 821.

rocks have been extensively faulted and intruded by igneous rocks, (Fig. 139). There are many deep mines in this district.

There is a connection between the coal-bearing formations along the Rhine, in Westphalia, Holland, Belgium and France. The coals occur in the Upper and Lower Carboniferous. In Westphalia and on the right side of the Rhine the beds are gently folded and but little faulted. On the left side of the river they are extensively faulted.

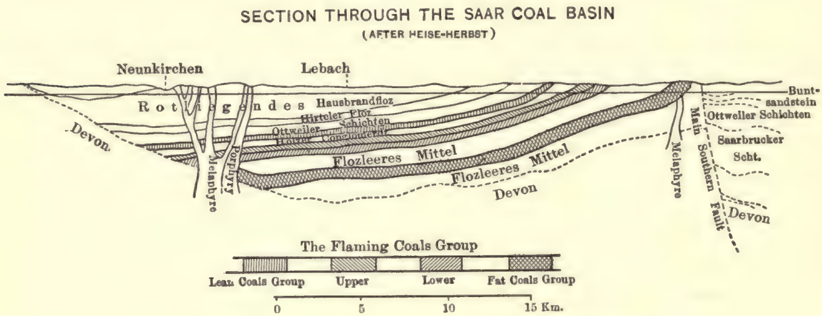

FIG. 139. — Section through the Saar basin.

The Coal Measures are buried to a depth of 700 meters in some places by Triassic, Cretaceous and Tertiary formations, and thick deposits of quicksand in the latter formations have made special mining methods necessary. On the left side of the Rhine the coal may reach a maximum aggregate of 32 meters, while on the right side the maximum thickness is about 30 meters with a maximum of thirty-three seams.

The main feature in the Lower Silesian districts is the depth of the basin, which exceeds 2000 meters in the center, and the Coal Measures are deeply covered by Cretaceous and other rocks. The basin is extensively faulted and crushed and igneous intrusions are abundant, with the result that considerable coal has been coked by natural processes. The mines are very gaseous. The coal is chiefly Upper Carboniferous but to some extent Lower Carboniferous in age. The coal is described as being platy (probably splint coal), fibrous and dull, and some of it is cannel coal.

Upper Silesia is a very important field, the second in Germany in importance. It is noted for the number and thickness of its seams. They are not so deeply buried as those of the Lower Silesian dis-

trict, not being over 150 meters below the surface, but the Carboniferous strata are very thick. They reach 7000 meters in the southwestern part of the district. The coals are Upper Carboniferous in age and the strata may be divided into a lower marine group (Randgruppe) and an upper brackish group (Muldengruppe). It is near the base of the latter that the thick coal seams occur. In the western part of the district there are said to be 477 seams containing an aggregate of 272 meters of coal, 124 of these seams being workable and carrying 172 meters of coal. In the eastern part are 105 seams of which 30 are workable, and they contain 62 meters of coal. The Upper Silesian field extends into what were formerly parts of Russia and Austria. It is highly folded but little faulted.

Coal mining has been carried on in Saxony since the tenth century and the better seams are practically exhausted in the Lower Carboniferous strata. The coal is now procured on a small scale from the Upper Carboniferous and Permian formations.

Lignite occurs extensively in Prussia and the North German States, especially in the Saxony-Thuringia district. The beds range from Eocene to Miocene in age. These lignites have been extensively employed for briquetting and for the production of by-products, such as gas, oils and paraffin.

Brown coals running from Miocene to Pleistocene in age occur in parts of Bavaria, and a small deposit of Oligocene age in this province is believed to be of undoubted drift origin.

Austria.[1] — There are three main coal-bearing areas in Austria. These are in the Alps, at the foot of the Alps, and in northern Austria. In the Alps there are coals of Carboniferous, Triassic, Jurassic, Upper Cretaceous and Miocene age. The Miocene coals are lignites, the seams reaching a maximum of 12 meters in thickness. The others are bituminous and occur for the most part in thin seams although mined in many places. Along the foot of the Alps important reserves of lignite occur in the Miocene rocks.

In parts of what was formerly northern Austria extensive deposits of lignite of Oligocene and Miocene age and also considerable beds of Upper Carboniferous coal are found in the middle Bohemian

[1] Petrascheck, W., Die Kohlenvorrate Osterreichs. Coal Resources of the World, Vol. III, p. 1013.

fields. Thick and numerous coal seams occur near the Prussian boundary but they are covered deeply in most areas by later rocks.

Hungary.[1] — Hungary, so far as known, is deficient in coal deposits. She has lignite, subbituminous and bituminous coal. The lignite and subbituminous coals occur in the Jurassic, Cretaceous, Tertiary and Quaternary formations and the bituminous coals in the Carboniferous and Jurassic. The brown coals or lignites are the only really important coals commercially. A considerable amount of the lignite formerly belonging to Hungary is in Croatia and Slavonia.

Bosnia and Herzegovina.[2] — The deposits of these states, like those of many other countries in southern Europe, have not been fully developed. Coals occur in Carboniferous, Permian, Triassic, Cretaceous and Tertiary formations, but the principal resources of these provinces are in the lignites of Tertiary age in the Zenica-Sarajevo, the Ugljevik-Priboj and the Baujaluka areas in the vicinity of Sarajevo, in Bosnia. In the Tuzla basin northeast of Sarajevo there are important Pliocene lignites with seams reaching 10 to 20 meters in thickness.

Serbia.[3] — Like the last-named states, Serbia has coal ranging from Carboniferous to Tertiary in age. The upper part of the Coal Measures lies on crystalline rocks and carries a few seams of mineable coal which in many places is impure and requires picking and washing. The Upper Cretaceous carries good seams of coal and also rests on crystalline rocks. The Jurassic coals are dirty but otherwise of fair quality. The Cretaceous and Tertiary coals are lignites. The mineral deposits of Serbia are as yet poorly developed.

Roumania.[4] — The most important coal deposits of Roumania are the Pliocene lignites and subbituminous coals of the Comanesti basin. A little anthracite is mined in the Carboniferous of the Carpa-

[1] De Papp, Charles, Les Ressources Houillères de la Hongrie. Coal Resources of the World, Vol. III, p. 961.

[2] Katzer, F., Die Kohlenvorrate Bosniens und der Hercegovina. Coal Resources of the World, Vol. III, p. 1075.

[3] Milojkovitch, F. A., Die Kohlenvorkommen Serbiens. Coal Resources of the World, Vol. III, p. 1093.

[4] Marzec, L., and Tanaseseu, I., Les Réserves de Charbon de la Rumanie. Coal Resources of the World, Vol. III, p. 1107.

thians. There is also some Mesozoic coal. The anthracite coal is of little importance. Roumania has apparently not developed her coals to any great extent and very little seems to be actually known regarding her real reserves.

Montenegro. — This state carries some good bituminous coal of Carboniferous age, one seam on the Albanian frontier reaching over 6 feet in thickness. Little attempt has been made to develop mining operations.

Greece. — Coal is mined in Greece only at Coumi, but lignite deposits of Tertiary age are widely distributed. The actual reserve is placed at 10,000,000 metric tons and the probable reserve at three times this figure. With the redistribution of lands in Europe, Greece will receive from Turkey in Europe the principal coal field of that country, lying near Keshan. This coal is of bituminous rank and some of it resembles a hard cannel. There is also considerable Tertiary lignite on the Marmora coast and at Telvino and Triano.

Bulgaria.[1] — Bulgaria has extensive seams of coal although they have not been developed and little attempt has been made to estimate her reserves. The coals are of three varieties, anthracite, bituminous coal and lignite. The anthracite lies in the Isker valley and while it is comparatively dirty and the seams are thin the volatile constituents are less than 4 per cent. It is Carboniferous in age. Bituminous coal of Cretaceous age is found in much-folded rocks in the Balkan basin. This coal is used in making briquets and in coking. It is very gassy. The seams are comparatively thin.

The Tertiary lignites and subbituminous coals are widely distributed and there are six main fields. In some places seams range up to 12 feet in thickness.

Turkey.[2] — Turkey has retained practically no coal lands in Europe. In Asia Minor there are a number of important fields of Carboniferous and Tertiary age. Along the Aegean and the Sea of Marmora there are good Miocene and Pliocene lignites which are mined locally. On the Asiatic coast of the Black Sea there are bituminous coals in the Lower Carboniferous, or Culm, and in the Westphalian and Stephanian series of the Coal Measures. The seams are numerous although not thick, and mining has

[1] Bontchew, G., Coal Resources of the World, Vol. I.

[2] Dominian, Léon, Coal Resources of the World, Vol. I.

been carried on at a number of places. Some areas have been greatly faulted. There is considerable coal, some of it anthracite, in the eastern part of Asia Minor, in the provinces of Bitlis and Erzoom. In the latter province lignite is mined. Lignite is also mined in Syria, near Beirut. Coal has been mined to a small extent in Mesopotamia.

Poland. — The Dombrova basin contains many thick seams, especially those in the Reden group of rocks where one seam reaches 12 meters in thickness. The rocks are Carboniferous in age, (Pennsylvanian) and the system is thick. Much faulting has occurred. The upper seams contain much ash and in many places the coal is mined in open pits as the measures lie near the surface in parts of the basin. The coal of Paleozoic age is bituminous, but the northern part of the basin contains extensive lignite deposits which are also mined. Other smaller basins which are not well known occur in this country, as well as in a small corner of the Upper Silesian field which lies mostly in Germany.

Russia.[1] — As indicated in the table showing the resources of Europe our information regarding the coal fields of Russia is rather indefinite since very little knowledge has been gained concerning the actual reserves. There are apparently very large resources in anthracite. The best-known basin is the Donetz which has furnished most of the coal mined. This is the most important Russian area and there are about 135 workable seams in the Lower and Upper Carboniferous strata in this field. This basin is so folded and faulted as to make mining conditions difficult in many areas. The fuel is bituminous coal and anthracite, the latter forming about 13 per cent of the output (Plate XVII.)

The Lower Carboniferous rocks form a great arc where they outcrop and approach the surface in the Moscow district. The main seams occur in the central part of the basin and they are known chiefly from borings because they are deeply buried by Carboniferous limestones. The coal is chiefly bituminous but some boghead, or cannel coal occurs.

Considerable bituminous coal mining is carried on along the west slope of the Ural Mountains in folded Lower Carboniferous rocks.

[1] Tschernyschew, Th., and others, The coal fields of Russia. Coal Resources of the World, Vol. III, p. 1149.

Plate XVII. — The coal fields of European Russia.

Similar conditions exist in Siberia along the east slope where in addition to bituminous coal there is a great deal of lignite mined in the Mesozoic and Tertiary formations and some anthracite is dug from closely folded basins in Carboniferous rocks.

The Caucasus district contains coal of Jurassic and Miocene age, the former bituminous coking coal and the latter lignite. The Turkestan coals are of little importance so far as known but they are in age Carboniferous, Rhaetic and Jurassic. The coals vary from coking bituminous to anthracite.

Among the other districts, those of Sudjensk and Kuznetzk give promise of being important as there is over 100 feet of coal in about seventeen seams. The coal varies from high-volatile gas coal to semi-anthracite and is Carboniferous in age. Numerous undeveloped areas of Permian coal-bearing rocks are known to occur along the Yenisei River but they have not been extensively prospected. The coals are bituminous in character.

Considerable amounts of coal of Jurassic and Tertiary ages, varying from bituminous coking coal to lignite, occur in the Irkutsk and other basins. The Russian Sakhalien carries coals of Upper Cretaceous to Pleistocene age and of bituminous to lignite in character. Finland is without commercial coal deposits although small quantities of anthracite have been found. Tertiary lignites are widely distributed over European and Asiatic Russia.

Sweden, Norway and Spitzbergen.[1] — Sweden has only a small coal field, in the province of Skane, in the south. The fuel is high-volatile bituminous to subbituminous coal and it occurs in Jura-Trias formations (Rhaetic-Liassic) associated with fire clays. The seams vary from 6 inches to 3 feet in thickness. The coal is mined at a number of places and the estimated reserves amount to about 115,000,000 tons. Sweden's production of coal supplies less than 8 per cent of her requirements and the remainder of her supply is imported.

Norway has no coal except a little on some of the northern islands. On Andö Island a seam of high-ash cannel coal, 1 meter thick occurs in Jurassic rocks. It has not been mined. Buren Island contains coal of Devonian age not yet worked. This is probably the oldest known coal in the world.

[1] Coal Resources of the World.


COAL AREAS OF ASIA
Tertiary Coals
Mesozoic Coals
Paleozoic Coals
SCALE OF MILES
300 150 0 150 300 450 600
Longitude
East
ATLANTIC
OCEAN
ARCHANGEL
SEA
KARA SEA
SPITZBERGEN
London
Berlin
Gulf of Bothnia
BALTIC SEA
White Sea
Petrograd
E U R O P E
Dnieper R.
Don R.
Volga R.
Ural R.
Troiskoi
Obi R.
Irtysh R.
Bobrovsky
Tobolsk
Egarshino
Ilyinskaia
Athens
Dardanelles
Marmora
Aegean
Constantinople
Smyrna
Heraclea
BLACK SEA
Tchemishgvedek
T U R K E Y
ARMENIA
GEORGIA
Tiflis
Erzerum
Baku
CASPIAN SEA
CYPRUS
MEDITERRANEAN SEA
Port Said
Suez Canal
ISTHMUS OF SUEZ
PALESTINE
Aleppo
SYRIA
Damascus
MESOPOTAMIA
Euphrates R.
Tigris R.
Bagdad
Bassora
Tabriz
Teheran
P E R S I A
Ispahan
Yezd
Kerman
Shiraz
Bushire
Persian Gulf
BAHRIEN Is.
Ormuz Str.
Gulf of Oman
Maskat
O M A N
Aral Sea
Sir Daria
Amu Daria
Lake Balkash
Tashkend
Kohan
AFGHANISTAN
BALUCHISTAN
Khelat
Punjab
Kashmir
Indus R.
Sutlej R.
Palana
HEDJAZ
Mekka
RED SEA
A R A B I A
Mocha
Aden
Gulf of Aden
A F R I C A
ARABIAN SEA
Narbada
Satpura Basin
Surat
Daman
South Rewah
Gondwana Bas
Bombay
Godavari
Basin
Godavari R.
Haidarabad
Kistna R.
GOA (Port.)
Madras
Bangalore
Trichinopoli
Karikal
Palks Str.
C. Comorin
G. of Manaar
CEYLON
Colombo
I N D I A N O

Plate XVIII. —

Coal fields of Asia.

Spitzbergen has been known for many years to contain considerable deposits of good coal, and mining operations have been carried on for a number of years by several small companies and by one large American concern. The island is almost covered with snow and ice most of the year, but sufficient information has been collected to fix the age of the coal deposits as Carboniferous, Jurassic and Tertiary. The only valuable Carboniferous coal so far located is at the head of Ice Fiord, where a seam 7 meters in thickness occurs. The Jurassic coals so far as known are unimportant. The Tertiary coal occurs near the base of the Miocene and is a good quality of subbituminous to bituminous coal. It is mined on Advent Bay by an American company. All shipping must be done during about three summer months owing to the unfavorable weather conditions. The ground is said to be frozen to a maximum depth of about 400 meters but the Tertiary rocks in this area are thick and the mining operations are carried on without great hardship in spite of about four months of continual darkness. On account of the scarcity of coal for domestic and industrial purposes in that part of the world the Spitzbergen output finds a ready market.

Asia

Asia is well supplied with coal although little is yet known regarding very large areas of that continent. The following table indicates the resources of the continent by countries and provinces in the various kinds of coal, and the accompanying map of the continent shows the distribution of the coals, (Plate XVIII.)

This table brings out two important points. One is the enormous resources of China in anthracite, although it seems probable that considerable coal classed as anthracite may be nearer semianthracite and semibituminous coal than true anthracite. In any case China leads the world by a tremendous margin in this commodity. The other point is the lack of definite knowledge regarding the continent's coal deposits. A few of the other countries, especially Siberia, undoubtedly have large reserves which are little known.

[1] COAL RESOURCES OF ASIA (IN MILLIONS OF METRIC TONS)

	Actual Reserve (1 metric ton = 1.1023 short tons)			Probable Reserve			Total
	Class of Coal			Class of Coal			
	A Anthracite and semi-anthracite	B and C Bituminous coals	D Subbituminous coals and lignites	A	B and C	D	
Corea......	7	1	5	33	B 4 C 9	22	81
China:							
Chili......	6785	B 6201 C 292		3,242	B 5,490 C 658		
Shantung..	1360	B 2842		640	B 2,241		
Shansi.....	240	B 123		299,760	B 414,217		
Shensi.....					B 1,050		
Kansu.....					B 5,129		
Honan.....				6,575	B 2,700		
Kiangsu...				10			
Anhui.....					B 187		
Hupei.....					B 117		
Chekiang..				18	B 6		
Chekiang..					B 120*		
Kiangsi....		B 325			B 3,070		
Fukien....				80*			
Kuangtung	498			256	B 255		
Kuangsi...					B 500		
Hunan....				48,000	B 42,000		
Szechuan..				20,000	B 60,000	500	
Kueichou..					B 30,000		
Yunnan...					B 30,000	100	
	8883	9783		378,581	597,740	600	995,587
Japan:							
Mesozoic coals......	4			37	B 5		
Tertiary...					C 5		
Karafuto.		C 17			C 1,345		
Hokkaido		C 336			C 2,106	233	
Honsu....	1	C 1	67	20	C 14	478	
Kyushu ..		C 542			C 2,374		
Taiwan...					C 385		
	5	C 896	67	57	6,234	711	7970

* Estimated by Kinosuke Inouye.

RESOURCES OF ASIA (*Continued*)

	Actual Reserve (1 metric ton = 1.1023 short tons)			Probable Reserve			Total
	Class of Coal			Class of Coal			
	A Anthracite and semi-anthracite	B and C Bituminous coals	D Subbituminous coals and lignites	A	B and C	D	
Manchuria..		B 31 C 378		68	B 223 C 508		1,208
Siberia.....				1	B 66,034	107,844	173,879
Indo-China.				20,002			20,002
India: Bengal, Bikai and Orissa.....		B 48			B 53,037 C 210		
Central India......					B 22,657		
Central Provinces		B 24 C 30	222		B 246	2,327	
Mesozoic and Tertiary...		C 119	3		C 28	50	
		221	225		76,178	2,377	79,001
Persia......					B 1,858		1,858
Total in Asia.......	8895	11,310	297	398,742	748,788	111,554	1,279,586

[1] From Coal Resources of the World, Vol. I. Estimate based on all seams less than 4000 feet deep and more than 14 inches thick, together with all seams between 4000 and 6000 feet deep and more than 2 feet thick, of workable coal. For description of classes see Classification of Coals, Chapter V.

China.[1] — The coal deposits of China are widespread. A very large area occurs in northern China covering most of the southern part of the province of Shansi, and another large field is found in the south covering parts of Hunan, Kueichou, Yunnan and Szechuan provinces. The age of the coals is Permo-Carboniferous, Rhaetic (Triassic), Jurassic and Tertiary, and the coals vary from lignite to anthracite. Some of the lignite is considered as Pliocene in age. The anthracite and other low-volatile coals occur in areas which are

[1] Drake, N. F., and Kinosuke Inouye, The coal resources of China. Coal Resources of the World, Vol. I, pp. 129–214.

more folded or compressed than the others, and considerable areas have been so crushed as to be almost unmineable. It is stated that in the Sieu River district in Hunan province, where much anthracite is mined, the seams of anthracite average 15 feet in thickness, and one seam, apparently of anthracite, is 50 feet thick. There is a large amount of good coking coal in the country.

Korea.[1] — Coal has been mined in Korea for many years but on a small scale and in a primitive way. The coals are of Paleozoic (apparently Carboniferous), Jurassic and Tertiary age. The Carboniferous coals so far discovered are of little importance but little is known about the possibilities of the rocks of this age. The Jurassic coals are most important. The Tertiary coals are lignites. Most of the coal mined is semianthracite. It is powdery, and is sent to Japan where it is made into briquets. Japan takes nearly all the production and most of the coal used in Korea is imported.

Manchuria.[2] — Manchuria has large resources in coal and there are a large number of small mines operated in a primitive way. Large operations are, however, being carried on in the important Fu-Shun field. The age of the coal is Carboniferous, Jurassic and Tertiary. The coals range from low grade bituminous to semianthracite. Most of the coal mined is from the Tertiary and it varies from subbituminous to bituminous. In this field one of the seams has a remarkable thickness and mining has been carried on for many centuries. It is stated that coal was mined here for a porcelain factory 600 or 700 years ago and that it was also used for copper smelting possibly as far back as 3000 years ago. Mining was prohibited by the government in the eighteenth century. The main seam in the Chien-chin-chai section varies in thickness from 130 to 200 feet with nearly a hundred thin partings aggregating about 20 feet. The quality of the seam varies considerably where folded, shrinking to 75 feet; and the partings increase to an aggregate of 70 feet in 130 feet of coal. The coal is subbituminous to bituminous and is low in sulphur and ash.

Japan.[3] — Mining of coal has been carried on in a primitive way in Japan for centuries, but about 1868 real, active mining began

[1] Kinosuke Inouye, Op. cit., p. 215.
[2] Kinosuke Inouye, Op. cit., p. 239.
[3] Kinosuke Inouye, Op. cit., p. 279.

under foreign engineers. The center of the coal-mining industry is in northern Kyūshū and large mining plants are also in operation in Hokkaido. Chikuhō, which is considered the richest and most important area, is well developed, and the Miike field is developing rapidly. Japan exports a good deal of coal and imports little although the imports from China are growing.

The coals of Japan are Triassic (Rhaetic), Jurassic, and Tertiary in age. The Rhaetic and Tertiary are of most importance, the latter being the best of all. Most of the Mesozoic fields are small and scattered and they have suffered much from folding and igneous intrusions. In the Tertiary the best coals occur in the Miocene. There is some lignite in the Pliocene. Some semianthracite coal occurs in the Mesozoic formations and natural coke occurs near igneous intrusions. Most of the coal mined is bituminous, much of it high-volatile. There is considerable coking coal.

The Ishikan coal fields are remarkable for the number of seams and their thickness. In the lower series of the Tertiary there are said to be as many as 150 seams, lens-shaped, and ranging from a few inches to 60 feet in thickness. The coal is bituminous.

India.[1] — Very little definite information is obtainable regarding the extent of the coal deposits of India. They occur in the Gondwana system, of Permo-Carboniferous age, and in the Tertiary, both in the Eocene and Miocene. There are unimportant and little-known areas in the Jurassic and Cretaceous. The older coals occur only in the Damuda series of the Lower Gondwana system. The Damuda series overlies the Talchir series, which is of glacial origin. The conditions in India strongly resemble those of South Africa and Australia where the coal deposits of the Permo-Carboniferous group are indirectly associated with glacial deposits and there are the same types of plants in the Glossopteris flora.

The main Gondwana fields occur in the following provinces: Bengal, Bihar and Orissa, Central India, Central Provinces and the Nizam's Dominions, the most important being those of Bengal, Bihar and Orissa. Active operations are carried on in the Raniganj, Giridih and Jherria fields. The coal is of bituminous quality,

[1] Hayden, H. H., The coal resources of India. Coal Resources of the World, Vol. I, p. 353. See also Memoirs Geol. Survey of India, Vol. XLI, by R. R. Simpson.

a good deal of it being of inferior grade. The seams have been in many places intruded, broken and altered by igneous rocks.

In the Umaria field of Central India mining is regularly carried on. In the Central Provinces there are three basins, Sarguja and Chattisgarh on the northeast, the Satpura and Chindwara basin on the northwest and the Godavari basin extending for nearly 300 miles down the Godavari and its tributaries. The possibility of the rocks of the Sarguja basin connecting with the Satpura basin and these again with those of the Godavari beneath the Deccan trap has been suggested. This would give tremendous reserves not yet exploited or computed. The Mesozoic and Tertiary coals occur in Assam, and there is a group of collieries near Margherita operating on seams aggregating 80 feet of coal. The coal is friable and high in sulphur. In Baluchistan a colliery is operated at Khost, but the seams of this district are thin and limited. Burma so far as known has little good coal.

With regard to the countries adjacent to India, it is reported that Afghanistan apparently has large coal deposits, but little is known regarding them. Thibet has no coal so far as known.

Persia.[1] — Coal is widely distributed over Persia and is mined by primitive methods for local use, in a great number of places. Very little is known regarding the extent or quality of most of the seams.

British North Borneo[2]

The coal in this island is lignite and low-grade bituminous coal, and it is almost all of Tertiary age. The better coal is Eocene but there is some in the Oligocene, Miocene and Pleistocene formations. A number of mines are worked and the labor is chiefly Chinese, Malay and Javanese. At Brooketon in the State of Sarawak, there are five seams with thicknesses of 28, 26, 29, 5 and 2 feet respectively. The first two of these seams are worked. The beds are tilted up to 80 degrees. The coal is very low in ash, one analysis showing only 1.58 per cent, and sulphur is low. Spontaneous combustion occurs

[1] Rabino, H. L., The coal resources of Persia. Coal Resources of the World, Vol. I, p. 365.

[2] Evans, J. W., The coal resources of British Territory in North Borneo. Coal Resources of the World, Vol. I, p. 89. Also see Coal Mining in Borneo by James Roden. Trans. Inst. Min. Eng., Vol. 28, p. 240, 1904–05.

under favorable conditions and there is a large amount of water in the mines. This field apparently extends under the sea to the north end of the Island of Labaun. Some of the coal contains a large amount of resin which the natives use for lighting purposes. The Silimpopon coal field on the river by that name is near the coast and shipments can readily be made. There is little gas in the mines and open lights are used.

Dutch East Indies, or Netherlands India[1]

A large amount of coal is distributed through these islands. It is all Tertiary in age, Eocene and Pliocene. The coal is of lignitic and subbituminous rank. The production of the island of Sumatra amounts to about half a million tons a year and this comes chiefly from the Soegar area of the Ombilin field in which some seams reach a thickness of over 30 feet. The other field on the Sepoetih River is not of much importance. Java contains some coal but the seams are thin. Borneo has a much larger supply with more and thicker seams than the other islands. The probable resources of all the islands are probably about one billion tons.

The Philippine Islands[2]

The important deposits of the Philippines are all Tertiary, chiefly Miocene in age, and these coals are mostly lignitic and subbituminous, with a little coal of bituminous rank. The total known area underlain with coal seams amounts to about 53 square miles of which less than 7 square miles are of workable quality. There is a much larger unprospected area which will no doubt prove to contain valuable seams. The fields occur on the islands of Baton, Cebu, Mindanao, Masbate, Mindoro and Luzon. On Luzon Island the coal is around Sugud Bay, and on the Island of Mindanao it is on Sibuguey Bay in the southwest corner of the island. Of these fields those on Baton and Cebu islands are regarded as most important. On the former island there are estimated to be about 26,000,000 tons of subbituminous coal in two to eight seams, 3 to 12 feet thick. The western part of the field is highly faulted and folded.

On the island of Cebu the coals lie from 8 to 15 miles from the sea.

[1] Douglas, E. A., Coal Resources of the World, Vol. I, p. 95.

[2] Dalburg, F. A., Coal Resources of the World. Vol. I, p. 107.

The coal is subbituminous and it occurs in a series of faulted and folded Oligocene and Miocene strata over 2000 feet thick. Some of the seams reach a thickness of 15 feet. The coal on Mindanao and Polillo islands is classed as bituminous by Dalburg. That on Mindoro Island near Bulalacao is lignite and the seams, six in number, run up to 12 feet in thickness. On Sugud Bay, Island of Luzon, the seams of subbituminous coal vary from 10 to 27 feet in thickness. The beds are considerably folded in parts of the field.

The Philippine coals are used chiefly by inhabitants of the islands for domestic purposes and on ships, and in recent years several mines have been operated on a fairly large scale. In most cases these are controlled by American mining men. Scarcely any of the coal cokes well. The total resources of the islands are placed at: bituminous coal, 4,959,200; subbituminous coal, 31,285,200; and lignite (black) 30,092,000 metric tons. Apparently the black lignite mentioned in the reports would be largely classed as subbituminous coal in this country according to our present custom.

PLATE XIX. — The coal fields of Africa. (From "Coal Resources of the World," published by the 12th International Geological Congress, Toronto, Canada.)

CHAPTER XV

THE COAL FIELDS OF THE WORLD — AFRICA AND OCEANIA

Africa[1]

The Dark Continent is so large and there is so much of it which has not been thoroughly explored that anything like an attempt to accurately describe its coal deposits is impossible at this time. The accompanying map (Plate XIX) shows the distribution of the coals so far as known and the following table gives the estimates of the resources as compiled by the International Geological Congress in the year 1913.

RESOURCES OF AFRICA

	Actual Reserve (In millions of metric tons) (1 metric ton = 1.1023 short tons)			Probable Reserve (In millions of metric tons)			
	Class of Coal			Class of Coal			Total
	Class A Anthracite and some dry coals.	Classes B and C Bituminous coals	Class D Subbituminous coals. Brown coals and lignites	A	B and C	D	
Belgian Congo.....					B 90	900	990
Southern Nigeria...			80				80
Rhodesia...........	2	B 306 C 37	74		B 119 C 31		569
South Africa:							
Transvaal..........					B 28,800 C 7,200		
Natal..............				4700	B 4,600		
Zululand...........				6000			
Orange Free State..							
Cape, Basuto and Swaziland.......				960	B 2,880 C 960		
				11,660	44,440		56,200
Total..............	2	343	154	11,660	44,680	900	57,839

For detailed description of classes see Classification of Coals, Chapter V. The reserves are figured on all seams which are 1 foot or over in thickness and less than 4000 feet deep; and on all seams of 2 feet and over which lie between 4000 and 6000 feet in depth.

[1] For detailed descriptions of deposits in Africa see Coal Resources of the World, Vol. II, pp. 375–428. Also Colonial Reports of the Museum of the Imperial Institute, London; Reports of the Department of Mines, Union of South Africa.

The geological ages of the coals of Africa are indicated in the table given below:

GEOLOGICAL AGES OF AFRICAN COAL DEPOSITS

	Egypt	Sudan	Abyssinia	East Africa Protectorate	Southern Nigeria	Madagascar	Nyassaland	Belgian Congo	Rhodesia	Transvaal	Cape of Good Hope	Natal
Pleistocene				L								
Tertiary	l b	l	l		L							
Upper Cretaceous					**B**							
Triassic, including Rhaetic											B s	b s
Permian						C				B		
Permo-Carboniferous							b	B	a B l			

A, Anthracite; S, Semibituminous; B, Bituminous; **B**, Subbituminous; L, Lignite; C, Cannel. Capital letter indicates important deposits, lower case unimportant or unworkable deposits.

The main coal fields of Africa are in the southern portions of the continent. Egypt has traces of lignite and bituminous coal but nothing workable. The Anglo-Egyptian Sudan is also lacking in workable coal although traces of lignite have been found. Abyssinia is little better off, but according to Dum and Grabham the natives mine coal near Addis Abbaba, the capital of Abyssinia. The East Africa Protectorate has no workable seams and Madagascar has a very limited amount so far as is at present known. In the Ianapera area of the island there are several seams reaching a maximum thickness of 8 feet 4 inches, and according to Bonnefond the coal is like cannel in character.

Southern Nigeria. — In southern Nigeria good subbituminous coal and lignite have been discovered. The former is probably of Cretaceous and the latter of Tertiary age. According to J. W. Evans, the best-known lignite areas occur in the vicinity of Onitsha and Asaba on the other side of the Niger River. In the latter locality six seams of lignite ranging from 8 to 20 feet in thickness have been examined, and this coal was found to make good briquets when tested in Europe and compared with the German lignites. The

seams of subbituminous coal reach nearly 6 feet in thickness and they outcrop in the escarpment about 45 miles east of the Niger River.

Nyassaland has very little coal which is sufficiently clean to be utilized.

Rhodesia. — The Wankie coal field is the only one in Rhodesia where coal is being mined. This field lies about 60 miles southeast of Victoria Falls on the railroad line to Bulawayo. The coal lies in the basin of the Zambesi River and like the other fields of South Africa it occurs in the Karroo series which apparently includes rocks ranging in age from Carboniferous to lower Jurassic, with no well-marked lines of division between them. The main coal-bearing formation is in the Lower Matobola which corresponds to the Ecca series of Cape Colony and the High Veld coal measures of the Transvaal. It lies just above the Dwyka conglomerate which is of glacial origin and usually regarded as of Permian age. Some geologists have considered at least some of the coal beds as of the same age as the Rhaetic of Europe. The seams are comparatively shallow in depth and vary from 1 foot to 12 feet in thickness.

The other fields of Rhodesia are the Mafungabusi lying just northeast of the Wankie field, the Lufua and Losita about 50 miles to the northwest of the latter field, and the Luano some 75 miles east of Broken Hill, on the railroad line. A small field near Tuli lies about 150 miles southeast of Bulawayo, and another on the Sabi River, near Sabi, 225 miles southeast-by-east from Bulawayo. These two fields are not on a railroad. It is supposed that a concealed field lies beneath the Victoria Falls basalts. The largest number of seams explored is in the Luano field where four have been found reaching an aggregate thickness of almost 18 feet. The thickest single seam is in the Wankie field and it runs up to 12 feet. The ash in the Rhodesian coals is high like that in the coals of South Africa, most of them running over 13 per cent.

Belgian Congo. — In the Belgian Congo there are two coal fields according to Renier, known as the Lukugo and Lualabo. The coals in the former field are regarded as of Permo-Carboniferous age and there are three flat-lying seams running over 10 feet in thickness. The coal is much lower in ash than much of that in South Africa. It averages around 10 per cent. In the Lualabo field the coal is

probably of Triassic age and there are several seams several feet in thickness. It is of inferior quality, however, as much of it is high in sulphur and very high in ash.

Union of South Africa. — The coal deposits of the Union of South Africa occur in the Karroo series which apparently includes rocks of Carboniferous, Permian and Triassic ages as they are known elsewhere. The seams usually lie within 200 feet above the Dwyka formation, the basal conglomerate of the Karroo series. Much of the coal is undoubtedly of Permian age and the same peculiar plant associations, usually known as the Glossopteris or Gangamopteris flora, which are found in the coal measures of India and Australia, are found here associated with the glacial deposits. The coal is practically all of the bituminous variety. A little lignite occurs in Cretaceous and Tertiary rocks but it is unimportant. One feature of most of the coal is the high ash content which runs from 6 to 30 per cent and averages between 10 and 15 per cent.

Transvaal: In the Transvaal the coal seams lie quite flat and occupy the high lands. They are usually of shallow depth, those worked being less than 400 feet deep. Many of the deposits occupy rather limited and isolated basins owing to the topographic conditions existing when they originated. They are also associated with coarse sediments, and some writers have considered that practically all of the South African coals are of drift origin, but in certain places stumps and roots are found in place beneath the seams indicating their *in situ* origin. In the Transvaal the main field is the Witbank or Middleburg and in it there are five known seams, giving an aggregate thickness of about 56 feet of coal. The average thickness of the seams worked runs around 10 feet, the maximum reaching about 20 feet.

Cape of Good Hope and Natal: In these provinces as in the Transvaal, the coal occurs in the Karroo series, but near the top. The Dwyka lies at the base of the Karroo in this region as elsewhere in South Africa and includes a thick glacial till. The coal occurs in the Molteno beds which are younger than the beds containing the coal in the Transvaal and they are apparently of Rhaetic (Triassic) age. The mines are worked by adits and the workings are confined largely to the portions of the seams near the outcrops, because many of the seams have been so broken up by intrusions of igneous rock

that their extent is uncertain. Much of the coal has been devolatilized and anthracitized by the heat of these intrusions. A considerable amount of the coal is semianthracite and it is high in ash, usually above 20 per cent. It is low in sulphur but a large amount of clinker is produced and it is said that this clinker is taken care of on the locomotives by specially designed fireboxes. There are some beds of lignite of Tertiary age but they are not of much importance.

In Natal, the coal, which is similar to that in the Cape of Good Hope Province, has been extensively intruded by igneous rocks and to quite an extent converted into semianthracite. Many of the mines are sufficiently gaseous to require the use of safety lamps.

The coal industry in Africa is very young and much will be added in the coming years to our knowledge of the geology and the coal resources of the continent. From the general character of the geological conditions on the continent, however, it seems improbable that Africa will ever be, comparatively speaking, a great coal-producing continent.

Oceania[1]

Oceania includes, for the purposes of this discussion, the continent of Australia and the islands of New Zealand and Tasmania.

Australia's reserves of high-grade coal are considerable, although they are smaller than those of Great Britain and very small compared with those of the United States or Canada, two countries to which Australia is almost equal in size. The table given below shows the estimated reserves for New Zealand and the various states of Australia. The latter country holds the record for the thickest coal seams in the world. There are two seams of brown coal in Victoria, which are 266 and 227 feet, respectively, in thickness.

[1] For comprehensive reports see The Coal Resources of the World, Vol. I. Also Coal-fields and Collieries of Australia by F. Danvers Power (Critchley Parker). Handbook for Australia, British Assn. Adv. Sci. 1914. Reports of the various state Geological Surveys and Departments of Mines.

COAL AREAS OF OCEANIA

140
150
160
170
P A C I F I C O C E A N
10°
EQUATOR
0°
NEW GUINEA
(BRITISH)
Torres Strait
SOLOMON
ISLANDS
10°
Cape York
Somerset
CAPE YORK PENA.
Princess Charlotte Bay
C.Flattery
Cooktown
CORAL SEA
NEW HEBRIDES
ISLANDS
FIJI ISLANDS
VETI LEVU
Bowen
Flinders R.
Hughenden
Prosperpine
Mackey
20°
NEW CALEDONIA
LOYALTY ISLANDS
QUEENSLAND
St.Lawrence
Mt.Morgan
Brisbane
Barwon R.
30°
Darling R.
NEW SOUTH WALES
Lachlan R.
Newcastle
Sydney
Murrumbidgee R.
Edward R.
Murray R.
VICTORIA
Melbourne
Portland
North Cape
NORTH
Auckland
ISLAND
East Cape
MAHIA PENINSULA
40°
Cook Str.
Wellington
TASMANIA
Hobart
Blenheim
SOUTH
NEW ZEALAND
ISLAND
Christchurch
Dunedin
140° from Greenwich 150°
160°
170°

[1]COAL RESOURCES OF OCEANIA

(In millions of metric tons. 1 metric ton = 1.1023 short tons.)

	Actual Reserve			Probable Reserve			Total
	Class of Coal			Class of Coal			
	A Anthracite and some dry coals	B and C Bituminous coals	D Brown coals and lignites	A	B and C	D	
Australia:							
New South Wales......					B 118,439		
Victoria......		B 40			B 12	31,114	
Queensland...	99	B 1766 C 165	66	560	B 11,011 C 751	800	
West Australia			153			500	
Tasmania.....					B 65 C 1		
	99	1971	219	560	130,279	32,114	165,242
New Zealand...		B 26 C 363	612		B 99 C 423	1,863	3,386
	99	2360	831	560	130,801	33,977	168,628

[1] These figures are based on seams 1 foot and over to a depth of 4000 feet; and 2 feet and over between 4000 and 6000 feet in depth. Coal Resources of the World, Vol. I. For description of classes of coal, see Classification of Coals, Chapter V.

Geological age of coals: The geological ages of the coals in Oceania vary from Carboniferous to Tertiary, the most important fields being Permo-Carboniferous (Permian). The latter are closely related to the coal deposits of India and South Africa and to some of those of South America. These deposits are characterized by the same peculiar plant associations, as Gangamopteris, Glossopteris and Rhacopteris are among the outstanding fossil plants of the Australian coal measures. Lepidodendron, so abundant in the Coal Measures throughout the rest of the world is present in the Devonian and Carboniferous rocks in Australia but absent in the Permo-Carboniferous, as the violent changes in climate wiped out this and related genera and ushered in the Glossopteris flora. The same interesting glacial conditions prevailed in Australia in the Permo-Carboniferous

as in India and South Africa and the same difficulty is experienced in trying to separate the Carboniferous from the Permian.

The other geological systems carrying important coal seams are the Triassic in Tasmania, the Jura-Trias in Queensland, the Upper Cretaceous in Queensland and New Zealand, the Miocene in Victoria and the Tertiary in New Zealand. The rank of the coal varies from bituminous and anthracite in the Permo-Carboniferous to bituminous and lignite in the Mesozoic and lignite in the Tertiary formations.

New South Wales.[1] — The coals of this state are of high grade and are bituminous in rank. They are valuable as gas, domestic and steaming coals. Much of the coal is of good coking quality. There are four important fields, the Maitland, Newcastle, Illawarra or Southern, and the Lithgow or Western field. The coal in all these fields is of Permo-Carboniferous age and the strata are divided as follows, in descending order:

	Thickness in feet.
(1) Upper or Newcastle Coal Measures with twelve seams of coal varying from 3 to 25 feet in thickness with aggregate of 35 to 40 feet workable coal. Glossopteris predominates over Gangamopteris...	1400–1500
(2) Dempsey series. Fresh water deposits without coal...........	2200
(3) Middle, or Tomago, or East Maitland Coal Measures with six	

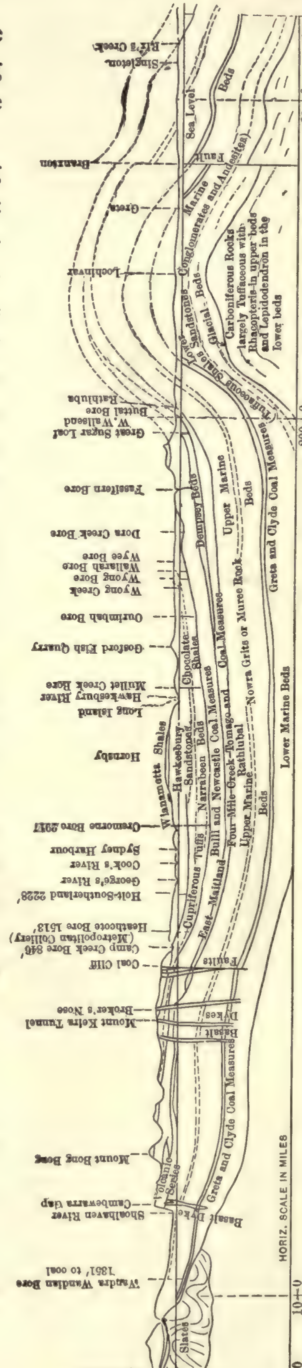

FIG. 140. — Structure section through the main coal basin of New South Wales. (Geological Survey of New South Wales.)

[1] Pittman, E. F., The mineral resources of New South Wales, 1913.

	Thickness in feet.
seams of coal 3 to 7 feet in thickness and aggregating 18 feet of workable coal.	500–1800
(4) Upper Marine series with glacial erratics in shales.	6400
(5) Lower or Greta Coal Measures with approximately 20 feet of workable coal in two seams, the Upper seam 14 to 32 feet thick and the Lower seam 3 to 11 feet thick.	100– 300
(6) Lower Marine series, containing much igneous rock and beds of glacial till at base. The rocks of the Carboniferous system are marine and fresh-water sediments with an abundance of igneous rock, and in parts of Australia are 20,000 feet thick. They are not coal-bearing.	

The Newcastle field has been the most important producer in the state but many of its collieries are already exhausted. In some places the mines extend beneath the sea. Some seams have been intruded with granite which has produced natural coke and nigger-head coal. In the Illawarra and Lithgow fields the coal occurs in the Newcastle series. This series is continuous from Newcastle to Illawarra and again from Sydney westward to Lithgow. At Sydney Harbor the upper seam is worked at a depth of 2882 feet.

New South Wales contains a large amount of oil shale known in Australia as *kerosene shale* and resembling the Torbanite of Scotland. The seams occur as lenses, sometimes reaching about a mile in extent, and from a few inches to about 4 feet in thickness. They are of Permo-Carboniferous age and the organic matter in them comes from the spores of plants.

Queensland. — This is the second most important state in Australia in coal reserves. The coal is almost all bituminous except a few million tons of semianthracite in the Dawson River field. There is some lignite, but this is of comparatively little importance. The coals are mostly of Permo-Carboniferous age, although the bulk of the coal so far worked is Jura-Trias in age. The Burrum field is considered to be of Cretaceous age, probably Lower Cretaceous. The Blair Athol field carries a seam of good clean coal 66 feet thick at a depth of only 120 feet below the surface. This coal is Permo-Carboniferous in age.

Victoria. — The coal resources of Victoria have not been very fully determined. There is some bituminous coal of Jurassic age but the main reserves are in the Miocene brown coal and the thick-

est seams known occur in this state. At Morwell a bore hole passes through 780 feet of brown coal in a depth of 1010 feet of strata and there are three very thick seams running 266, 227 and 166 feet, re-

FIG. 141. — Thick series of Coal Measures on coast of New South Wales, at Shepherd's Hill. (Photo by E. S. Moore.)

spectively. This coal averages 35.08 per cent water; 29.24 per cent volatile matter; 33.28 per cent fixed carbon; and 2.40 per cent ash. It can no doubt be used for briquetting and in gas producers.

Tasmania. — Permo-Carboniferous coal in thin seams and high in sulphur has been mined a little for domestic purposes in the Mersey and Preolenna coal fields. Most of the coal mined comes from the Triassic formations which have suffered much faulting and which have also been much disturbed by intrusions of igneous rock. The coal is high in ash and it is not used much except for domestic purposes and on some of the railroads. Two collieries are at work near St Mary's and they together produce about 60,000 tons a year.

Considerable oil shale, known as *Tasmanite* shale, is found on the island and it is said to yield 40 to 50 gallons of crude oil per ton.

FIG. 142. — Collieries at the state mine, Port Elizabeth, New Zealand. (Photo by E. S. Moore.)

Western Australia. — The only productive field in this state is the Collie field lying south of Perth. This field is a block of Permo-Carboniferous measures about 50 square miles in extent. It lies at quite a shallow depth and is little folded or faulted although surrounded by faults, one on the southwest having a throw of about 2000 feet. The coal is friable, non-coking, subbituminous to bituminous in rank and partly of the splint variety. It has a high moisture content. The low fuel ratio of the coals in the Collie field is due to the lack of pressure exerted on these beds even though they occur in formations as old as the Permo-Carboniferous.

South Australia and Northern Territory. — South Australia contains some Jurassic coal in the Leigh's Creek field, and a small amount has been mined. It is, however, of poor quality. A seam 47 feet thick is said to have been penetrated at a depth of about 1500 feet. In the Great Australian Artesian Water Basin lignite occurs in the Lower Cretaceous and in the southern part of the state lignite of Tertiary age occurs in a number of places, but there has been little exploitation.

The Northern Territory, so far as known, has no important coal deposit.

New Zealand.[1] — New Zealand has inadequate fuel supplies for her future needs as at the present rate of increase in production her bituminous coal will be exhausted in less than fifty years. Her main reserve lies in the Tertiary brown coals. The seams are notably lenticular in form and they occur as if deposited around the margins of basins. There is a little anthracite in the South Island, in the folded and faulted areas and where the seams have been intruded by igneous rocks, but the quantity is very small. The geological age of the coal runs from Jurassic through the Upper Cretaceous and the Tertiary. Possibly there is some lignite of Pleistocene age. The thicknesses of some of the seams are as follows: 50 to 60 feet of brown coal in the Waikato district near Auckland; 53 feet of bituminous coal in the Buller-Mokihinui district; and 80 feet of lignite in Central Otago. As stated above, however, the seams are very irregular in thickness, and they are commonly lenticular in outline.

Antarctica

T. W. E. David[2], who spent considerable time in Antarctica on geological work with the Shackleton expedition, states that the coal-bearing rocks in this great continent may cover something less than 12,000 square miles. Coal has been found at the head of Beardmore Glacier and at Mackay Glacier, 605 geographical miles apart. The coal-bearing area is a long, narrow "horst" bounded by large faults. As many as six seams with 22 feet of coal have been seen. The enclosing rocks are believed to be of Permian age and the coals are therefore related to those of Australia.

[1] Marshall, P., Geology of New Zealand, Wellington, N. Z., 1912.
[2] Coal Resources of the World.

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